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MECHANICS

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Electrical Merchandising

INDUSTRIAL PHYSICS

MECHANICS

BY

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FIRST EDITION

McGRAW-HILL BOOK COMPANY, Inc.
NEW YORK: 370 SEVENTH AVENUE
LONDON: 6 & 8 BOUVERIE ST., E. C. 4
1922

$1 / 75

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PREFACE

The present trend in education has created a demand for a series of textbooks in which the material presented is more closely connected with the every-day life of the student. This volume is the result of an attempt to provide a textbook in elementary, practical mechanics,—a textbook suitable for use in technical, industrial, vocational and evening schools.

The chief difficulty encountered in writing an educational book is the choice of material. The material presented here consists largely of notes used in class by the author. It has been tried out and has proven successful. Certain time-honored topics, usually included in similar books, have been omitted; there has been no sacrifice, however, of fundamental principles. The order of presentation has been found satisfactory. It may be changed, if desired, without impairing the value of the course. An attempt has been made throughout to keep the diction simple and understandable.

Attention is directed to the questions and problems at the end of each chapter or division. The questions depend upon the subject-matter preceding and are invaluable both for study and review. The problems are not difficult and, it is hoped, sufficiently generous in number. Experience has proven that problems are an excellent medium for clarifying misunderstandings on the part of the student. Arithmetic is sufficient for most solutions, although a knowledge of algebra and trigonometry will be helpful. A special chapter dealing with elementary trigonometry has been included.

The author makes no particular claim to originality. He has consulted various standard works freely and acknowledges his indebtedness to many of them. Care has been exercised to keep the book free from errors. In case errors have crept in, the author will be glad to have his attention called to them.

Criticism of scope and content will also be welcomed.

Certain chapters have been made possible through the hearty coöperation of various firms and manufacturing plants in furnishing information, photographs, electrotypes, etc. Grateful acknowledgment is made to the following: Brown and Sharpe Mfg. Co.; Central Scientific Co.; Cole Motor Car Co.; Curtiss Aeroplane and Motor Corp.; Dodge Sales and Engineering Co.; Edw. R. Ladew Co.; Fafnir Bearing Co.; Ford Motor Co.; Goodell-Pratt Co.; Goodyear Rubber Co.; Goulds Mfg. Co.; Hyatt Roller Bearing Co.; Keuffel and Esser Co.; L. E. Knott and Co.; Link-Belt Co.; L. S. Starrett Co.; Skinner Engine Co.; Timken Roller Bearing Co.; Whitney Mfg. Co.; Worthington Pump and Machinery Corp.; Yale and Towne Mfg. Co.

The author wishes to thank his colleagues, T. Gilbert McFadden, John H. Finn and Albert E. Dickie, for the valuable help they have given in the preparation of the manuscript. He also wishes to thank Frank E. Mathewson, Director of the Technical and Industrial Department, Wm. L. Dickinson High School, for suggestions and advice incident to the publication of the book.

L. R. Smith.

Jersey City, N. J.,
June, 1922.

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INDUSTRIAL PHYSICS

MECHANICS

CHAPTER I

INTRODUCTORY

1. Physics.—Physics is often defined as *the science of matter and energy,*—the science which attempts to explain the relation between physical phenomena and the causes producing them. Physics is conveniently divided into five parts: (1) *mechanics;* (2) *heat;* (3) *light;* (4) *sound;* (5) *electricity.* This volume deals with mechanics only, a knowledge of which is very useful in studying the remaining divisions of the subject.

2. Industrial Physics.—*Industrial physics* differs from the so-called *academic physics* in that its subject matter is more *practical.* It substitutes material of live value for certain time-honored topics which seem to have little or no connection with the life of the pupil. It is intended for serious, energetic students who wish to get a better training than has been possible with the material customarily presented.

3. Mechanics.—*Mechanics is that branch of physical science which deals with forces and their effects.* It includes a study of the action of forces on solids, liquids and gases. Mechanics may be divided into two distinct parts: *statics* and *kinetics.*

Statics deals with bodies so acted upon by forces that no motion results.

Kinetics deals with bodies so acted upon by forces that motion results.

4. Matter.—*Matter is anything which has weight or which takes up room.* Matter may exist in three different forms: *solids, liquids* or *gases.* Any material substance, such as steel, gold, water, air, etc., is composed of matter.

5. Energy.—*Energy is the ability to do work.* Gasoline possesses energy because it enables an internal combustion engine to do work.

6. The Molecule.—All matter is thought to consist of small particles called *molecules.* A molecule is defined as *the smallest particle into which a substance may be divided without destroying its identity.* For example, a molecule of water is written H_2O; two molecules of water is written $2H_2O$, etc. Suppose we have one hundred molecules of water or 100 H_2O; we can then divide it into 100 parts, each part being H_2O and having the characteristics of water. If we go beyond this in our division, we break up the molecule into oxygen and hydrogen, two gases which in no way resemble the original water.

Molecules are so minute that they are not discernible with the most powerful microscopes. It has been estimated by Lord Kelvin[1] that, if a quantity of water the size of a football were magnified to the size of the earth, the molecules would be between small shot and footballs in size.

7. The Atom.—A molecule is made up of *atoms.* By breaking up the water molecule (H_2O) we get the atoms H, H and O. These atoms in no way resemble the molecule of which they were formerly a part. The atom then, after the molecule, is the next step in the division of matter and is *the smallest particle of matter capable of entering into combination.*

8. The Electron.—According to the most recent investigations, the atom is a very complex structure. It is thought to be composed of a nucleus or positively charged vibrating particle surrounded by various negatively charged particles.

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[1] Sir William Thomson (1824–1907). One of the greatest of the nineteenth-century physicists. Born in Ireland. Fifty-three years professor of physics at Glasgow University. Noted for his work in heat and electricity.

These negative particles, called *electrons*, are very mobile and possess tremendous velocities, some approaching the velocity of light (186,000 mi./sec.). So far as is known, *the electron is the smallest division of matter.*

9. Kinetic Theory of Matter.—There is a well-substantiated theory that *all molecules are in constant vibration.* This is known as the *kinetic theory of matter.*

10. Physical Change.—*A physical change is one in which the substance does not lose its identity,* such as planing a piece of steel; melting a quantity of tin; forming steam from water, etc. It is evident, in each case, that the new form assumed has the same molecular constitution as the original.

11. Chemical Change.—*A chemical change is one in which the substance loses its identity.* If we burn a piece of coal, we find that it has been changed into ash and various gases, none of which resemble the original coal. Another example is the rusting of a nail. Rust is a combination of oxygen and iron and does not resemble the iron in any way.

12. Force.—*A force is anything that will cause a body to undergo a change of shape or a change in condition of motion.* For example, a force may elongate, compress, twist or bend a body; it may cause a body at rest to move; it may cause a moving body to stop; it may increase or decrease the velocity of a body; or it may cause a change in the direction of the motion.

13. Equilibrium.—A body at rest is in equilibrium, since its state of motion (zero) is constant; a flywheel rotating at a constant speed is in equilibrium, since its state of motion does not vary. *Equilibrium means a balanced condition, in which the state of motion does not change.*

14. General Properties of Matter.—There are certain characteristics that are common to all bodies. Such characteristics are called *general properties.* A few of the more important ones will be discussed.

Porosity.—All matter is *porous,* that is, a space exists between the molecules of all bodies. No two adjacent molecules are ever in contact. It has been proved that gold is porous by forcing water through it under heavy pressure. A teaspoonful of sugar may be put into a cup of coffee without appreciably increasing the cubical contents of the cup. This is explained by the fact that the sugar molecules penetrate the inter-molecular spaces of the coffee. A simple experiment will demonstrate that water is porous. A long glass graduate is nearly filled with water and the graduation coinciding with the water line is noted. If a few drops of alcohol are introduced into the water and the mixture is thoroughly shaken, it will be seen that the water line has not risen. This is because the alcohol molecules have arranged themselves in the inter-molecular spaces of the water.

Compressibility.—All bodies are *compressible.* Liquids are the least compressible and gases are the most compressible. Solids vary widely in this respect. Steel is difficult to compress, while wood is relatively easy to compress. When a body is compressed, the molecules are crowded closer together, causing the body to weigh less per unit volume. It is evident that compressibility is a direct consequence of porosity.

Indestructibility.—All matter is *indestructible.* In burning a piece of coal, we do not destroy the matter of which the coal is composed. The coal is converted into ash and various gases, but the original matter still exists in other forms.

Inertia.—Inertia, commonly treated as a force, *is a property of matter causing a body to resist any attempt to change its condition of rest or motion.* If a body is at rest, it resists any attempt to set it in motion. If a body is in motion, it resists any attempt to stop, increase or decrease its speed or to change the direction of its motion.

Elasticity.—Whenever a body suffers a change of size or shape, it manifests a tendency to resume its original size or shape. This property is known as *elasticity.* Steel and copper are highly elastic, while substances like rubber are less elastic. Even a mass of putty is slightly elastic. The elasticity of a body is measured by the amount of its resistance to a change of size or shape.

Cohesion.—Cohesion enables like molecules to hold together.

It is greatest in solids, least in gases, and decreases with a rise in temperature. *Tensile strength* depends upon cohesion and is measured by the effort necessary to rupture tensionally a body of unit cross-section. Strictly speaking, cohesion is a property of matter. We may think of it, however, as the force binding like molecules together.

Adhesion.—Adhesion enables unlike molecules to hold together. Water clinging to a glass rod and paint clinging to a piece of wood are examples. Although adhesion is a property of matter, we may think of it as the force binding unlike molecules together.

Mass.—Mass refers to the amount of matter a body contains. It is measured by the resistance that a body offers to a change of state of motion. The inertia of a body is proportional to its mass. Mass should not be confused with weight. The weight of a body may vary, but the mass will remain constant. A body weighing 10 lb. at the earth's surface, will weigh practically nothing at the earth's center. The amount of matter will be the same in each case.

15. Specific Properties of Matter.—*Specific properties* are common to certain bodies only. They enable us to distinguish one substance from another. Following is a discussion of a few of the more important ones.

Tenacity.—Tenacity is the relative measure of cohesion in various bodies. The tenacity of steel is very great; copper is less tenacious. A carbon steel casting may require as high as 80,000 lb./in.^{2} to rupture it tensionally. Alloy steel is even more tenacious. Rolled copper has a tensile strength of approximately 40,000 lb./in.^{2}

Hardness.—Hardness is the resistance a body offers to being scratched or worn by another. A body that will scratch another is said to be the harder of the two. The diamond is the hardest of all known substances. If a body is moving rapidly, it will cut into another body which is harder. The cutting ability of an emery wheel depends upon the fact that the emery is very hard and that the particles of emery are moving with great speed.

Hardness should not be mistaken for *brittleness.* Brittleness is aptness to break under the application of small forces. Vanadium steel is *hard* and *tough*, while glass is *hard* and *brittle.* Steel is made very hard and brittle by heating it to a red heat and then plunging it into a bath of water or oil. By reheating and cooling slowly, the steel will become *soft* and *flexible.* The latter process is called *annealing.* The desired hardness for cutting tools is brought about by *tempering.* The steel is reheated slowly until it assumes a certain color and is then plunged into the bath of oil or water Lathe tools are reheated to a pale yellow color (approx. 400°F.)., while saws are reheated to a dark blue color (approx. 600°F.).

Ductility.—Ductility enables substances to be drawn out in the form of a wire. Platinum may be drawn into a wire .00003 of an inch in diameter. Glass is so ductile that it may be drawn out into fine threads and the threads woven into cloth.

Malleability.—A body which may be hammered, rolled or pressed into thin sheets is said to be malleable. It is possible to make gold leaf .000003 of an inch in thickness, in which case the gold is transparent.

Questions and Problems

1. Define mechanics, statics, kinetics, matter, energy.

2. Distinguish clearly between the molecule, atom and electron.

3. What is meant by the kinetic theory of matter?

4. Define and give examples of a physical change.

5. Define and give examples of a chemical change.

6. What is a force? What effects may it produce?

7. What is meant by equilibrium? Give examples.

8. What is the difference between general and specific properties of matter?

9. Define and discuss: porosity, compressibility, indestructibility, inertia, elasticity, cohesion, adhesion, mass.

10. Define and discuss: tenacity, hardness, brittleness, ductility, malleability.

11. What is meant by annealing? Tempering?

CHAPTER II

MEASUREMENT AND MEASURING INSTRUMENTS

SECTION I. MEASURES AND WEIGHTS

16. The English System.—In the United States we still employ the so-called *English system* of measurement for everyday work. The *yard* is taken as the standard of length, the *pound* as the standard of mass (weight) and the *second* as the standard of time. In applied physics the *foot* (*⅓ of a yard*), the *pound* and the *second* are often used as fundamental units. A system of measurement employing the three latter units is called the *foot-pound-second system.* It is usually spoken of as the *f.p.s. system.* The English system is inconvenient and has given way almost entirely to the *metric system* for purely scientific work. At present there seems to be a tendency toward the adoption of the metric system in this country for all purposes. The coming generation should thoroughly master the metric system, so that there will be as little confusion as possible when the change occurs.

17. The Metric System.—About the time of the French Revolution, the government of France appointed a commission to devise a system of weights and measures to replace the awkward system then in use. This resulted in the establishment of the metric system in France. It has since been made compulsory in most civilized countries, England and the United States being exceptions. The metric system is extremely easy to use on account of its simplicity and decimal scale. In scientific work the *centimeter, gram* and *second* are used as fundamental units. A system of measurement employing the three latter units is called the *centimeter-gram-second system.* It is usually referred to as the *c.g.s. system.*

The *meter* (*m.*) was adopted as the standard of length in the metric system. It was intended to be $1/10{,}000{,}000$ of the distance from the Equator to the North Pole, measured on the meridian of Paris. This distance was computed incorrectly, however, and the standard meter to-day is the distance between two transverse scratches on a bar of platinum-iridium at a temperature of 0°C. This bar is preserved in the archives of France and replicas have been sent to all civilized countries. The meter is 39.37 inches long. Our yard is officially defined as $3{,}600/3{,}937$ of a meter. The meter is divided into 10 equal parts or *decimeters;* 100 equal parts or *centimeters;* and 1,000 equal parts or *millimeters.* The centimeter, due to its more convenient size, is universally used in scientific work. Figure 1 shows the relation of the centimeter and inch.

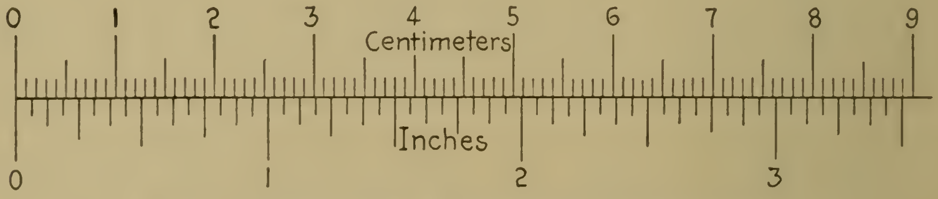


FIG. 1.—Comparison of the centimeter and inch.

The metric standard of mass (weight) is the *kilogram* (*Kg.*). It was intended to be *the mass of one cubic decimeter* (*dm.*^{3}) *of pure water at a temperature of* 4°*C.* Due to a very slight error, this relation is not exactly true. It is close enough, however, for all practical purposes. The prototype kilogram is a cylinder of platinum-iridium kept in the archives of France, copies of which have been furnished to all civilized countries. The *gram* (*g.*) or one thousandth of a kilogram is taken as the fundamental unit. The gram is divided into 10 equal parts or *decigrams;* 100 equal parts or *centigrams;* and 1,000 equal parts or *milligrams.* Our pound avoirdupois is equivalent to 453.5924277 grams. For practical work, 454 grams is used. The kilogram is equivalent to about 2.2 pounds. Figure 2 shows the practical relation of the pound and kilogram.

The unit of capacity in the metric system, both dry and wet, is the *liter* (*l*). It is equivalent to the volume of *a cube one decimeter on a side* and is approximately the same as a quart. The liter is divided into 10 equal parts or *deciliters;* 100 equal parts or *centiliters;* and 1,000 equal parts or *milliliters.* For practical purposes, a liter of water may be considered to weigh one kilogram. Hence *one cubic centimeter of water weighs one gram.*

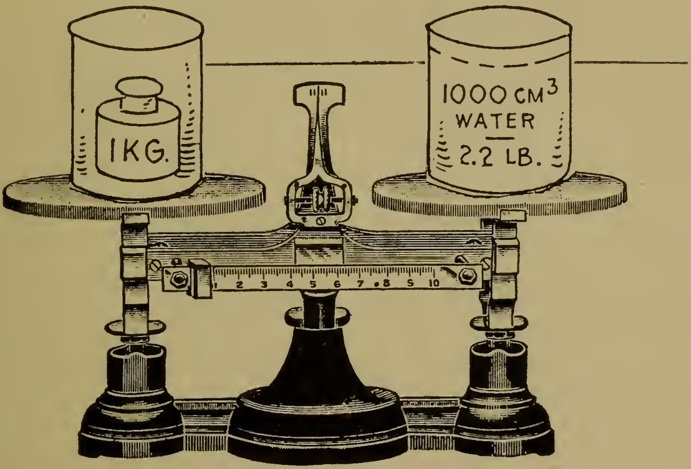


FIG. 2.—One kilogram weighs 2.2 pounds and just balances 1,000 cubic centimeters of water.

The unit of time in the metric system is the *second.* It is defined as $\frac{1}{86,400}$ *of the mean solar day.*

The following tables will familiarize the student with the essential parts of the metric system. Heavy type is used for the more common units.

MEASURES OF LENGTH

10 **millimeters** (mm.) = 1 **centimeter** (cm.)
10 centimeters = 1 decimeter (dm.)
10 decimeters = 1 **meter** (m.)
10 meters = 1 dekameter (Dm.)
10 dekameters = 1 hectometer (Hm.)
10 hectometers = 1 **kilometer** (Km.)
10 kilometers = 1 myriameter (Mm.)

MEASURES OF SURFACE

100 **square millimeters** (mm.^{2}) = 1 **square centimeter** (cm.^{2})
100 square centimeters = 1 square decimeter (dm.^{2})
100 square decimeters = 1 **square meter** (m.^{2})
100 square meters = 1 square dekameter (Dm.^{2})
100 square dekameters = 1 square hectometer (Hm.^{2})
100 square hectometers = 1 square kilometer (Km.^{2})

MEASURES OF VOLUME

1000 cubic millimeters (mm.^{3}) = 1 **cubic centimeter** (cm.^{3})
1000 cubic centimeters = 1 cubic decimeter (dm.^{3})
1000 cubic decimeters = 1 **cubic meter** (m.^{3})

MEASURES OF CAPACITY

10 milliliters (ml.) = 1 centiliter (cl.)
10 centiliters = 1 deciliter (dl.)
10 deciliters = 1 **liter** (1)
10 liters = 1 dekaliter (Dl.)
10 dekaliters = 1 hectoliter (Hl.)
10 hectoliters = 1 kiloliter (Kl.)

MEASURES OF WEIGHT

10 **milligrams** (mg.) = 1 **centigram** (cg.)
10 centigrams = 1 decigram (dg.)
10 decigrams = 1 **gram** (g.)
10 grams = 1 dekagram (Dg.)
10 dekagrams = 1 hectogram (Hg.)
10 hectograms = 1 **kilogram or kilo** (Kg.)
10 kilograms = 1 myriagram (Mg.)
10 myriagrams = 1 quintal (Q)
10 quintals = 1 **tonneau or metric ton** (T.)

The following *equivalents* should be memorized by the pupil. They are sufficiently accurate for all ordinary work.

1 meter = 39.37 inches (exact)
1 inch = 2.54 centimeters (approx.)
1 kilometer = .62 mile (approx.)
1 kilogram = 2.2 pounds (approx.)
1 liter = 1.06 liquid quarts (approx.)

QUESTIONS AND PROBLEMS

1. Give a brief history of the metric system.

2. Show why the metric system should be made compulsory in this country.

3. What is the f.p.s. system of measurement? The c.g.s. system?

4. Define: yard, foot, pound, meter, kilogram, gram, liter and second.

5. Why must the prototype meter be kept at a temperature of 0°C.?

6. What is the weight in grams of 10 $cm.^3$ of water?

7. On July 2, 1901, the Cornell Varsity Crew at Poughkeepsie rowed 4 mi. in 18 min., 53⅕ sec., establishing the record for the course. What was the average speed in meters per sec? In kilometers per hr?

8. The amateur record for the hundred yard dash is 9⅗ sec. Express the speed in meters per sec. In kilometers per min.

9. The muzzle velocity of a projectile was 2,000 ft. per sec. How many meters per hr. was this?

10. An aviator ascended to a height of 30,000 ft. State the altitude in meters.

11. Light travels with a velocity of 300,000 kilometers per sec. Give the equivalent velocity in feet per sec.

12. If the barometer reads 760 millimeters, what will it read in inches?

13. The wheel base of an automobile is 120 inches. What is it in centimeters?

14. The diameter of the earth is about 8,000 miles. Express the diameter and circumference of the earth in kilometers.

15. A fly wheel two meters in diameter rotates at the rate of 200 r.p.m. What linear distance will a point on the circumference travel in 4 minutes?

16. An iron casting weighs 200 lb. What is its weight in kilograms? in metric tons?

17. An aluminum block weighs 10 Kg. What is the weight in pounds?

18. How many cubic centimeters are there in a granite block 2.5 meters on a side?

19. Compute the number of cubic inches in a cubic meter.

20. A gasoline tank holds 15 gallons. Express its capacity in liters.

21. A tank is 2 × 2 × 6 meters. How many grams of water will it hold?

22. The drip vat of a steam power plant is 2 × 2 × 3 meters. How many cubic feet of drip will it hold?

23. How many quarts are there in a cubic meter?

SECTION II. MEASURING INSTRUMENTS

18. The Steel Rule.—A 6 in. flexible *steel rule*, graduated in sixty-fourths of an inch on one side and millimeters on the other, should be the personal property of each student. It is not expensive to buy, is practically indestructible, and may be carried in the pocket.

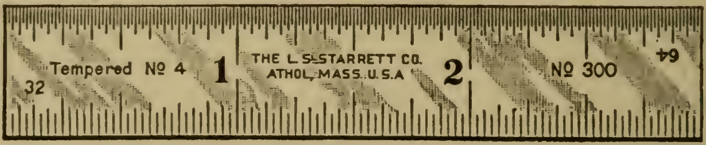


Fig. 3.—Steel rule.

19. The Protractor.—*Protractors* are used to measure angles and are either adjustable or non-adjustable. One or more large adjustable protractors should be in every laboratory, and the student should own a small brass or steel protractor of the non-adjustable type. The exact method of measuring an angle may be seen from a study of the accompanying diagrams.

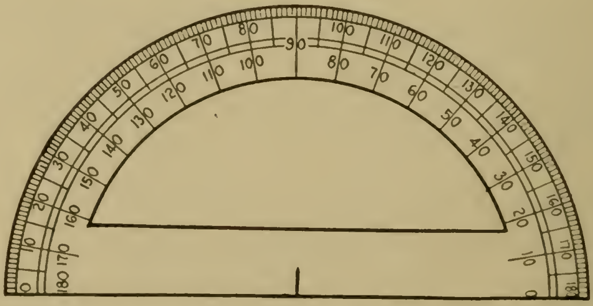


Fig. 4.—Ordinary form of protractor.

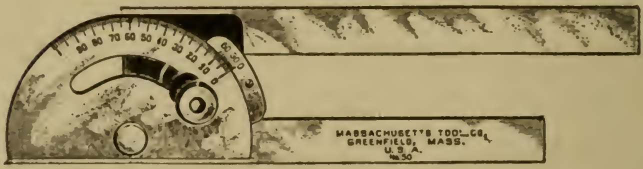
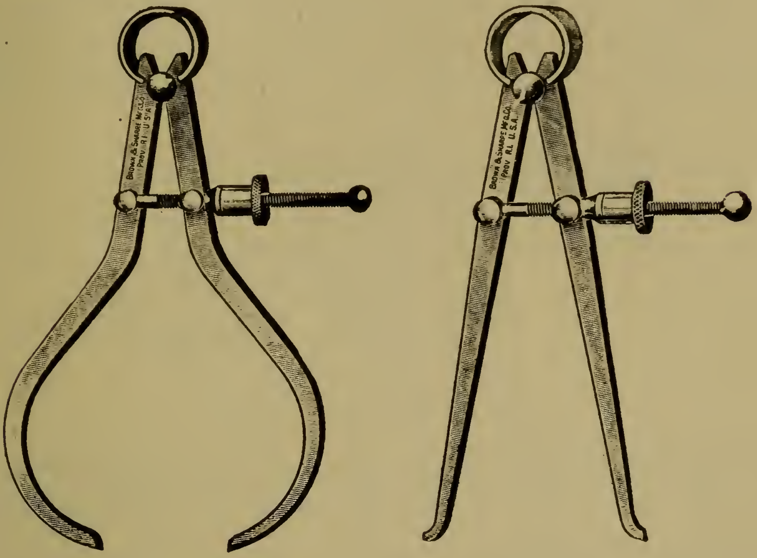


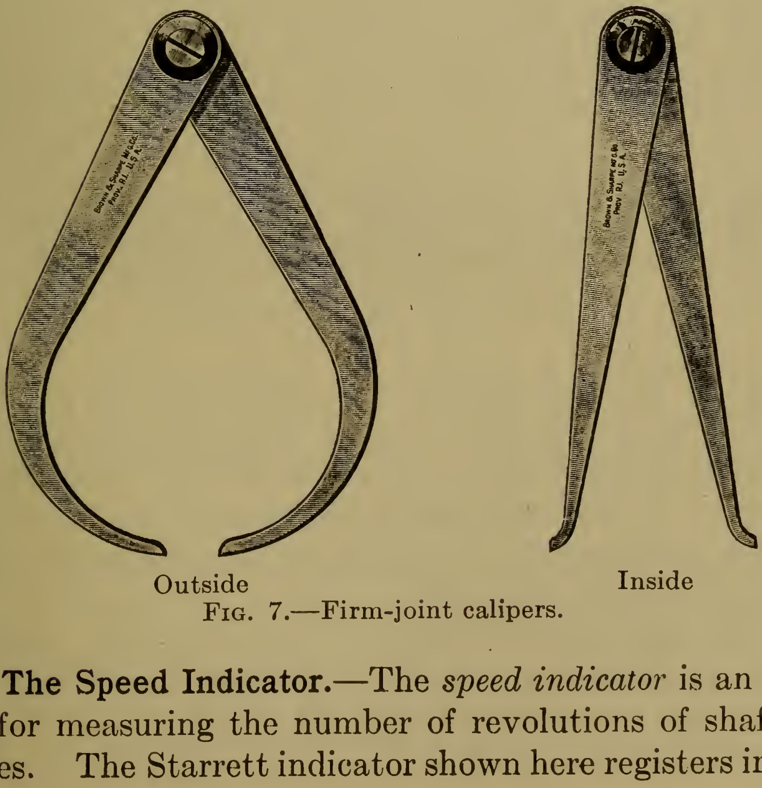
Fig. 5.—Adjustable protractor.

20. The Ordinary Caliper.—*Calipers,* shown herewith, are used in taking external and internal measurements when a high degree of accuracy is not necessary. They are either of the "spring" or "firm-joint" type. *Outside* and *inside* calipers, of different capacities, should always be available for laboratory work.



Outside Inside

Fig. 6.—Spring calipers.



Outside Inside

Fig. 7.—Firm-joint calipers.

21. The Speed Indicator.—The *speed indicator* is an instrument for measuring the number of revolutions of shafts and spindles. The Starrett indicator shown here registers in either direction up to 100. The rotating disc carries a raised knob which should coincide with the knob on the dial at the start. The disc is carried around by friction; hence it is an easy matter to set it back to zero. Each complete rotation of the disc indicates 100 r.p.m. of the shaft or spindle under test. In principle, the indicator is a worm and worm wheel. The student will be able to use the indicator without detailed instructions.

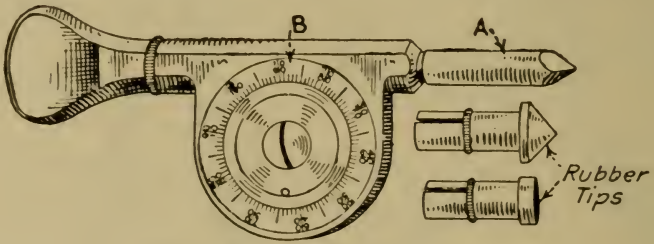


Fig. 8.—Speed indicator.

22. The Slide Rule.—The *slide rule* is a device to facilitate the solution of numerical problems. Its accuracy is sufficient for most kinds of work. Problems involving *multiplication, division, roots, powers, trigonometric functions,* etc., may be solved with a great saving of time. Students will find the slide rule of great convenience for both home work and class work. It is comparatively expensive, yet it is hoped that a majority of students will be able to own one. The Polyphase rule shown in the diagram, has proven very satisfactory. Complete and detailed instructions are furnished by the manufacturer with each rule.

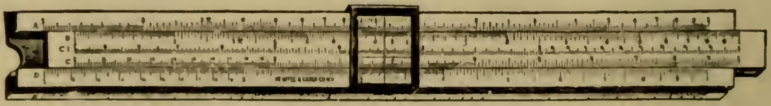


Fig. 9.—Polyphase slide rule.

23. The Micrometer Caliper.—The *micrometer caliper* is used to take measurements when very fine readings are desired. The type shown in Fig. 10, is for external measurements. Micrometer calipers may be procured in various sizes, some reading as high as 24 in. Ordinarily, they read only to *thousandths* of an inch, but by careful estimation of scale divisions, finer readings are obtainable. They are also graduated metrically with corresponding accuracy. The one described here will read accurately to a thousandth of an inch.

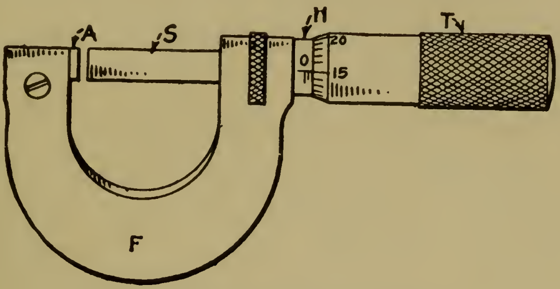


Fig. 10.—Micrometer caliper.

The micrometer caliper consists of the following essential parts: the *frame* (*F*); the *anvil* (*A*); the *spindle* (*S*); the *sleeve* (*H*); and the *thimble* (*T*).

The sleeve is graduated in *tenths* of an inch. The grabuations are labelled 1, 2, 3, etc. Each numbered division is sub-divided into *four* equal parts or *fortieths* of an inch. The spindle has *forty* threads to the inch and rotates in a fixed nut.

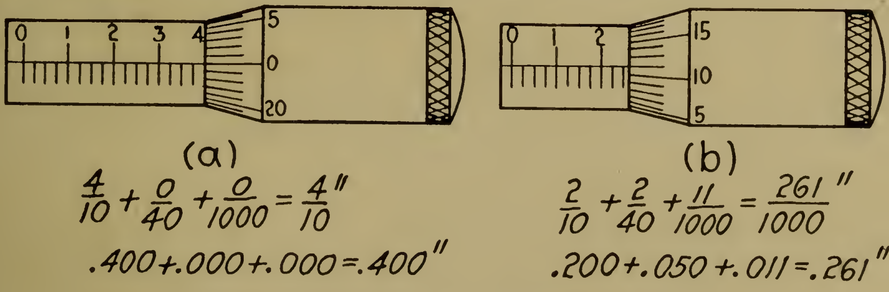


Fig. 11.—Reading a micrometer caliper.

Hence *one full rotation* of the thimble will cause the spindle to move *one fortieth* of an inch to the left or right. Since the bevelled edge of the thimble is divided into *twenty-five* equal parts, a movement of *one* scale division on the bevel will cause a spindle movement of *one twenty-fifth* of *one fortieth* or *one thousandth* of an inch.

In using the micrometer caliper, the body to be measured should be placed in the jaws of the instrument and the thimble rotated until *light contact* is made. If the caliper is *forced*, inaccurate readings will result. A *ratchet device*, automatically stopping the spindle at the proper pressure, is often provided. The "spindle" reading plus the "thimble" reading will give the dimension sought.

The diagrams in Fig. 11 represent the relative positions of the spindle and thimble for the readings indicated. The student should study these diagrams very carefully.

24. The Vernier Caliper.—The *vernier caliper*, like the micrometer caliper, is used when very fine measurements are required. The one shown below will read down to one thousandth of an inch. It is graduated in *thousandths* of an inch on the front and *sixty-fourths* of an inch on the back. Only the front will be discussed.

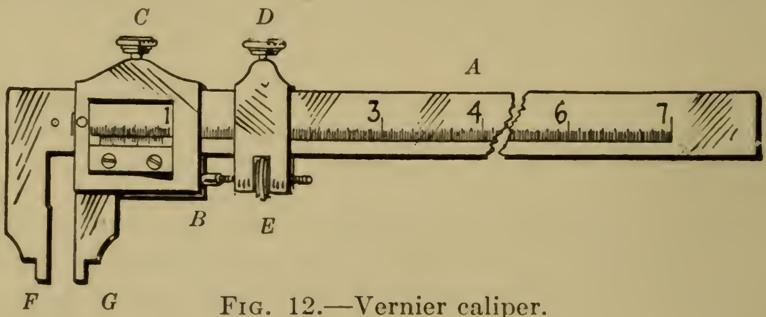


Fig. 12.—Vernier caliper.

Figure 12 shows the general construction of a standard vernier caliper. It consists of the following parts: the *beam* (*A*); the *slide* (*B*); the *binding screws* (*C* and *D*); the *adjusting screw* (*E*); and the *jaws* (*F* and *G*).

The beam (Fig. 13) is graduated in *inches* and is numbered 1, 2, 3, etc., large numbers being used. The *inches* are divided into *ten equal parts* or *tenths* of an inch and are numbered 1, 2, 3, etc., small numbers being used. The *tenths* are further divided into *four equal parts* or *fortieths* of an inch and are not numbered. The *smallest division* on the beam is, therefore, one fortieth (.025) of an inch.

The slide (Fig. 13) is divided into *twenty-five equal parts* and is numbered 5, 10, 15, 20 and 25. Each numbered part is sub-divided into *five* equal parts without numbers. There are in all, then, *twenty-five* small divisions on the slide.

By reference to Fig. 14, we see that *twenty-four* small divisions on the *beam* correspond in length to *twenty-five* small divisions on the *slide.* Hence a small division on the slide = $^{24}/_{25}$ of a small division on the beam = $^{24}/_{25}$ of .025 in. = .024 in. Further, we see that the *first graduation on the slide* differs from the *first graduation on the beam by* .001 in.; that the *second graduation on the slide* differs from the *second graduation on the beam* by .002 in., etc.

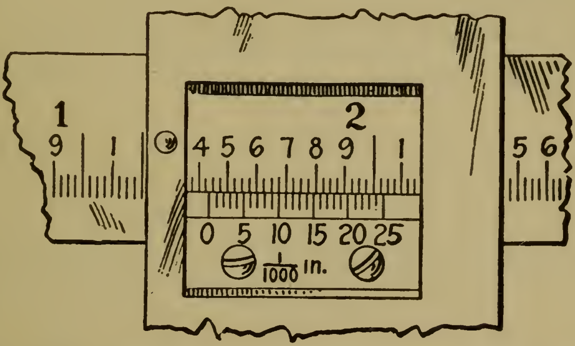


Fig. 13.—Vernier caliper, view of beam and slide.

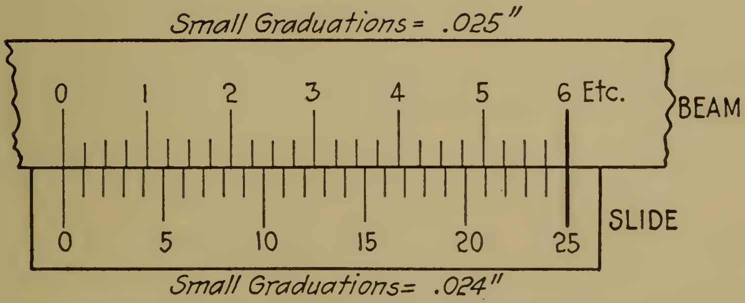


Fig. 14.—Vernier caliper, comparison of small graduations on beam and slide.

The following instructions should be observed in manipulating the vernier. The instructions are intended only for external measurements and refer to Fig. 12. After moving the slide over until both jaws nearly touch the object, the binding screw (*D*) should be screwed down. The fine adjustment (*E*) should be rotated until each jaw touches the object lightly. After screwing down the binding post (*C*) so as to lock the jaws, the reading may be taken.

To illustrate the reading of a vernier caliper, let us take an example and refer to Fig. 15. In measuring the diameter of a steel rod it was found that the *twenty-ninth* small division on the beam exactly lined up with the *eighteenth* small division on the slide. It is evident that the diameter of the rod is the *linear distance* represented by the *twenty-nine* small divisions on the beam less the *linear distance* represented by the *eighteen* small divisions on the slide, viz., .725 in. − .432 in. = .293 in.

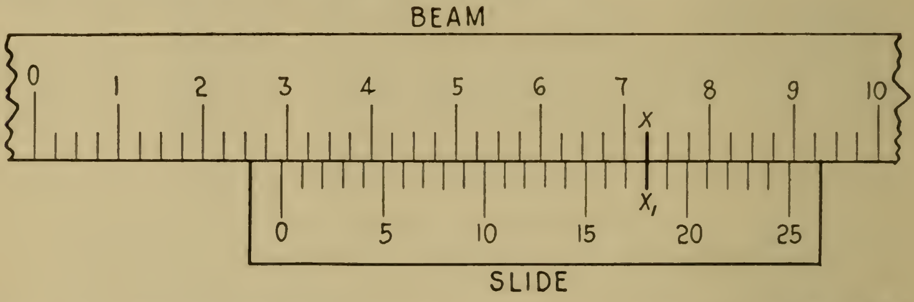


FIG. 15.—Vernier caliper, showing coincidence of graduations X and X_1.

Since the *zero* mark on the slide (Fig. 15) extends somewhat beyond the .275 in. mark on the beam, it will be seen that the diameter of the rod is also .275 in. *plus the distance to zero on the slide.* As the points of coincidence (X and X^1) are *eighteen* slide divisions beyond zero on the slide, then zero on the slide must extend .018 in. beyond the .275 in. mark on the beam. Hence the correct reading will be .275 in. + .018 in. = .293 in., the same as determined in the first method. The method last described should always be used as it is more direct.

To read the vernier caliper we may adopt the following rule: *Note and record the first small division on the beam to the left of zero on the slide. Add to this* .001 *in. for each small slide division up to the point where the beam and slide divisions coincide.*

QUESTIONS AND PROBLEMS

1. Describe two types of calipers used for approximate work.
2. For what is the micrometer caliper used? Describe its construction and operation.

3. For what is the vernier caliper used? Describe its construction and operation.

4. The following readings were obtained in reading a micrometer caliper: .240 in.; 1.361 in.; and 2.546 in. What is the sleeve and thimble reading in each case?

5. If the above readings were obtained with a vernier caliper, state in each case the point at which the beam and slide division coincided.

CHAPTER III

ELEMENTARY TRIGONOMETRY

25. Trigonometry Defined—Trigonometry deals with the relations which the sides and angles of a right-angled triangle bear to each other. An elementary knowledge of trigonometry facilitates the solution of many numerical problems. Hence it is very important for the student to gain a working knowledge of the subject.

26. Trigonometric Functions.—A trigonometric function is the ratio which one side of a right-angled triangle bears to another. There are six such relations. They are given here with respect to angle θ. The first three functions are sufficient for ordinary purposes.

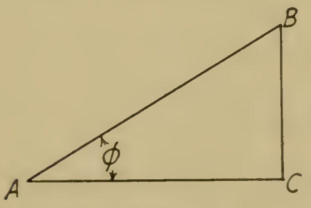


FIG. 16.

$$\frac{BC}{AB} = \frac{\textit{side opposite}}{\textit{hypotenuse}} = \textit{sine (sin) of angle } \theta.$$

$$\frac{AC}{AB} = \frac{\textit{side adjacent}}{\textit{hypotenuse}} = \textit{cosine (cos) of angle } \theta.$$

$$\frac{BC}{AC} = \frac{\textit{side opposite}}{\textit{side adjacent}} = \textit{tangent (tan) of angle } \theta.$$

$$\frac{AC}{BC} = \frac{\textit{side adjacent}}{\textit{side opposite}} = \textit{cotangent (cot) of angle } \theta.$$

$$\frac{AB}{AC} = \frac{\textit{hypotenuse}}{\textit{side adjacent}} = \textit{secant (sec) of angle } \theta.$$

$$\frac{AB}{BC} = \frac{\textit{hypotenuse}}{\textit{side opposite}} = \textit{cosecant (cosec) of angle } \theta.$$

27. Trigonometric Solutions.—Let us illustrate the solution of problems by the use of the sine, cosine and tangent. Referring to Fig. 17, we have a right angled-triangle. If the side *BC* is 5 inches in length, by actual measurement the other side will be 8.66 inches and the hypotenuse 10 inches. As long as the angles are kept constant, even if the lengths of the sides are changed, there will always exist the same numerical ratio between the lengths.

Solutions.—1 Suppose it is desired to find *BC*, knowing the angle *BAC* and the hypotenuse *AB*. *Solution:* $BC/AB = \sin BAC$. $BC = AB \sin BAC$. Referring to the trigonometric tables in the appendix, we find that the *sine* of angle *BAC* (30°) is .500. Hence, by substitution, $BC = 10 \times .500 = 5$.

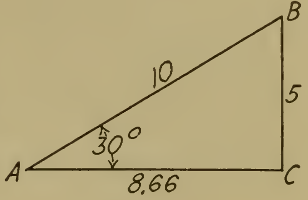


Fig. 17.

2. Suppose it is desired to find *AC*, knowing angle *BAC* and the hypotenuse *AB*. *Solution:* $AC/AB = \cos BAC$. $AC = AB \cos BAC$. By substitution, $AC = 10 \times .866 = 8.66$.

3. Suppose it is desired to find *BC*, knowing angle *BAC* and the side *AC*. *Solution:* $BC/AC = \tan BAC$. $BC = AC \tan BAC$. By substitution, $BC = 8.66 \times .577 = 4.996$. (Since the tables in the appendix are to three decimal places only, we get 4.996 instead of 5 as expected. Three place tables are accurate enough for ordinary purposes.)

4. Suppose it is desired to find angle *BAC*, knowing sides *AB* and *BC*. *Solution:* $\sin BAC = BC/AB$. $\sin BAC = 5/10 = .500$. By reference to the trigonometric tables, it is found that the angle to which .500 corresponds is 30°.

Questions and Problems

1. With what does trigonometry deal? Why is it important in mechanics?

2. What is a trigonometric function?

3. Name and define the six trigonometric ratios.

4. A guy wire attached to the top of a telephone pole is secured to the ground by means of a "dead man" and makes an angle of 60° with the ground. The wire enters the ground 18 ft. from the bottom of the pole. (*a*) How long is the wire? (*b*) How high is the pole?

5. A flag pole rope, when pulled 20 ft. away from the bottom of the pole, just touches the ground. If the rope pulley is 40 ft. above the ground, (*a*) how long is the rope? (*b*) What angle does it make with the ground?

6. The Woolworth building is 792 ft. high. An imaginary line, at an angle of 60° to the vertical, is drawn from the top of the tower to the ground. Assuming no change in altitude and no curvature of the earth, (*a*) how far horizontally from a point directly under the tower would the line strike the ground? (*b*) How long would the line be?

7. A ladder 30 ft. long is placed against a house at an angle of 48° to the horizontal. (*a*) How high is the top of the ladder above the ground? (*b*) How far is the bottom of the ladder from the house?

8. A shadow cast by the top of a monument 30 ft. high is 12 ft. long. What is the angle of the sun with reference to the ground?

9. A captive balloon 200 meters high is driven by the wind until the tie rope is at an angle of 80° to the ground. What is the second height of the balloon?

10. From a light house 50 ft. high, two rocks are seen in a direct line with the observer. If the rocks make angles of 60° and 70° respectively with the vertical at the top of the light house, how far apart are the rocks?

CHAPTER IV

GRAVITATION AND GRAVITY

28. Universal Gravitation.—It has been found that there is a mutual attraction existing between all bodies in the universe. For instance, there is an attraction between the masses of the earth and the moon, although they are separated by a distance of over 240,000 miles. The periodic rising and falling of the ocean waters, known as tides, is ascribed largely to the gravitational effect of the moon. There is also an attraction between the earth and the sun, the earth and the stars, etc. The effect is slight, however, due to the tremendous distances between them.

29. The Law of Universal Gravitation.—A study of gravitation led to an enunciation by Sir Isaac Newton[1] of the following law:

Between every two particles of matter in the universe there exists a mutual attraction which varies directly as the product of the masses and inversely as the square of the intervening distance.

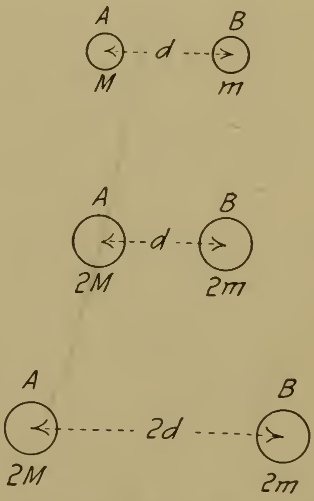


FIG. 18.—Attractive force between A and B in middle diagram is four times as great as in upper and lower diagrams.

The above law is called the *law of universal gravitation* and will be readily understood by reference to Fig. 18. A and B (upper diagram) represent two bodies with masses of M and m respectively and separated by a distance of *d*. The product of the masses is *Mm*. If the masses are doubled (middle diagram), their product will be 4 *Mm* and the mutual gravitational force will be increased 4 times. If, in addition, the distance between *A* and *B* is doubled (lower diagram), the gravitational attraction between them will be reduced to $\frac{1}{4}$ its former value. The attraction in the upper and lower diagrams is therefore identical. If the distance is tripled and the masses doubled in the upper diagram, the attractive force will be $\frac{4}{9}$ of its original intensity.

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[1] Sir Isaac Newton (1642–1727). Born in England. Buried in Westminster Abbey. Famous as a physicist, mathematician and astronomer. Professor of mathematics at Cambridge, member of Parliament and Master of the Mint. Responsible for the law of gravitation, the three laws of motion which bear his name, the bionomial theorem, the calculus and many discoveries in light.

Fig. 19. Plumb line.

30. Gravity.—The term *gravity* refers to gravitation in a restricted sense. Specifically, it means the *mutual attraction between the earth and bodies on or near the earth's surface.* Thus the force which impels bodies toward the earth is called the *force of gravity.*

The force of gravity tends to pull all objects towards the earth's center of mass. This point is approximately at the geometrical center of the earth (4,000 miles below the surface). The direction of the pull is conveniently determined by means of a *plumb line.* Ordinarily the plumb line points directly toward the earth's center of mass. It will be deflected slightly, however, if brought near a large mountain. A deflection will also take place if the cord is too long, due to the rotation of the earth. Ordinarily, deflections are too slight to have any serious effects and, for practical purposes, we may assume that the plumb line, if extended, would pass through the center of the earth. We say that the plumb line assumes a *vertical* position. Any line drawn perpendicular to the plumb line is said to be *horizontal.*

31. Weight.—The mass or quantity of matter possessed by a body remains constant, but the *weight* is subject to variation. The weight of a body is the *mutual attraction existing between the body and the earth.* For example, if a man weighs 175 lb. at a certain place on the earth, the earth is pulling the man toward its center with a force of 175 lb.; likewise, the man is exerting a pull of 175 lb. upon the earth. The maximum weight is at the earth's surface.

32. Bodies Above and Below the Earth's Surface.—From the law of universal gravitation, it follows that *the weight of a body above the earth's surface will be inversely proportional to the square of its distance from the center of the earth.* Algebraically:

$$W : w :: d^2 : D^2$$

Suppose we wish to know how much a body weighing 1,000 lb. at the earth's surface will weigh 1,000 miles above the surface. Employing the above proportion we have:

$$1{,}000 : w :: 5{,}000^2 : 4{,}000^2, \text{ from which } w = 640 \text{ lb.}$$

A body below the earth's surface will lose in weight due to the fact that the particles above the body exert a contrary attraction to that of the particles below. The resultant force acting on the body will be the difference between the two attractions.

As the polar diameter of the earth is less than the equatorial diameter, it follows that gravity is greater at the poles than at the equator. The effect of gravity is also lessened at the equator due to the centrifugal force set up by the earth's rotation. If the earth were to rotate 17 times as fast as it does, the force of gravity at the equator would be neutralized.

33. The Acceleration of Gravity.—Since the force of gravity varies from place to place, the acceleration imparted to falling bodies will vary slightly. A body at the equator will fall with less velocity than a body at the poles. Also, if two bodies fall an equal distance but strike the ground at different altitudes, the body striking at the lower altitude will have the greater velocity. The *acceleration of gravity* is the velocity a freely falling body will gain during each second of fall and will be written hereafter as "*g*." At the latitude of New York City (40.73°N.), the acceleration of gravity is 32.16 ft. per second per second or 980 cm. per second per second.

34. Center of Gravity.—Since all bodies are composed of small particles, it naturally follows that each particle is acted upon by gravity individually. Thus we may consider a body as acted upon by parallel forces, the sum of which constitutes the weight of the body. For convenience, we may assume that all of the separate forces may be replaced by a single force having the same effect as the joint action of the separate forces. The point at which the resultant force would be applied is called the center of gravity or center of mass of the body. *The center of gravity is the point at which the weight of a body may be considered concentrated.* If a body is suspended at its center of gravity, there will be no tendency toward rotation. The weight of a body is always taken as a separate force acting downward at the center of gravity.

35. Determination of the Center of Gravity.—In regular, homogeneous bodies, the center of gravity may be found geometrically. The center of gravity of a uniform lever is at its middle point; of a rectangle, the intersection of the diagonals; of a circle, the center; of a triangle, the intersection of the medians, etc. (See Fig. 20.)

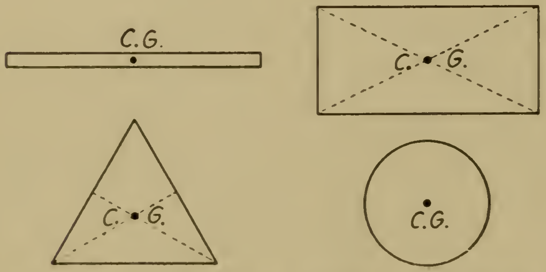

Fig. 20.—Center of gravity determined geometrically.

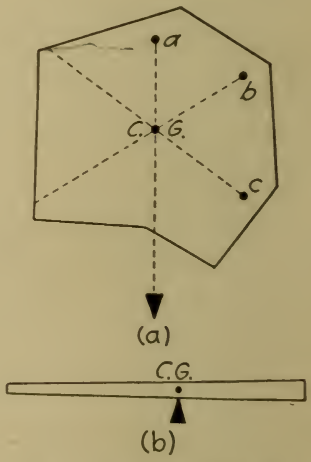

Fig. 21.—Center of gravity determined experimentally.

If the body is irregular in shape, the center of gravity may be determined experimentally. For example, suppose we have a piece of sheet zinc as shown in Fig. 21(*a*). The zinc is freely suspended from hole "*a*" and a plumb line dropped from the point of suspension. The center of gravity will be along this line which is marked. The zinc is then suspended from hole "*b*" and the previous operation is repeated. The center of gravity will be at the intersection of the two positions assumed by the plumb line. If a hole is drilled at the point of intersection, the sheet will remain fixed in any position. The center of gravity of levers, rods, etc., may be found by balancing over a knife edge (Fig. 21 (*b*)). More complicated determinations of the center of gravity are omitted as being beyond the scope of this book.

36. Equilibrium.—A body is said to be in equilibrium with respect to gravity when a vertical line from its center of gravity passes through the supporting base. If the vertical line passes outside of the supporting base, a rotation results and the body is overturned. There are three kinds of equilibrium; (1) *stable;* (2) *unstable;* and (3) *neutral.*

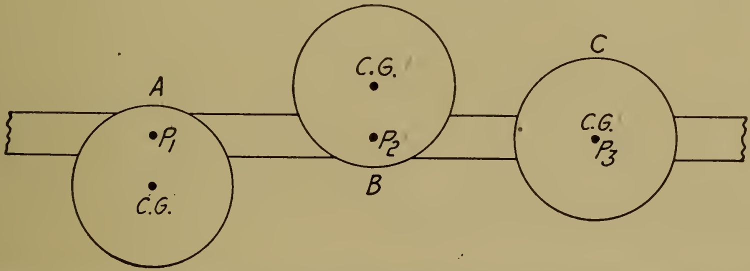

FIG. 22.—Bodies *A*, *B* and *C* are respectively in stable, unstable and neutral equilibrium.

The three kinds of equilibrium are illustrated in Fig. 22. *A*, *B* and *C* are metal disks with their centers of gravity as shown. If *A* is freely suspended at point P_1, it is said to be in *stable equilibrium.* If displaced, the body tends to resume its former position, due to the fact that any rotation necessitates a raising of its center of gravity. Since *B* is suspended at P_2, any displacement will lower the center of gravity and the body will not return to its first position. *B* is therefore in *unstable equilibrium.* *C* is suspended at P_3. Since this point coincides with the center of gravity, it is evident that a displacing force will neither raise nor lower the center of gravity and that the body will stay wherever it is put. *C* is therefore in *neutral equilibrium.*

37. Stability.—A body is said to possess *stability* if it is difficult to overturn. Stability depends upon the size of the supporting base and the location of the center of gravity. *A large supporting base and a low center of gravity give a body great stability.* A racing yacht must be well ballasted to keep it from overturning. Cargo ships are always ballasted when crossing the ocean with no cargo aboard. The center of gravity is thus kept low. Tall chimneys are not highly stable, as the supporting base is relatively small and the center of gravity relatively high. The stability of a body is measured *by the amount of work necessary to overturn the body.* It is found by multiplying the weight of the body (concentrated at the center of gravity) by the vertical distance through which the center of gravity is raised. Thus in Fig. 23, the body *ABCD* has a stability of 5 foot-pounds.

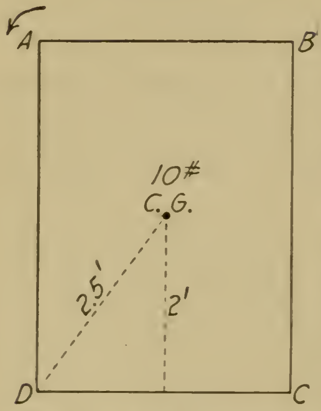

Fig. 23.—Body *A-B-C-D* has 5 ft.-lb. of stability.

Questions and Problems

1. What is meant by universal gravitation?

2. State and illustrate the law of universal gravitation.

3. Distinguish between gravity and weight.

4. For what is a plumb line used? Does it always point to the center of mass of the earth? Explain.

5. Why does a body weigh most at the earth's surface?

6. State the formula for finding the weight of bodies above the earth's surface.

7. State two reasons why a body weighs less at the equator than at the poles.

8. What is meant by the acceleration of gravity? What factors affect it? What is the acceleration at New York City?

9. Explain fully what is meant by the center of gravity.

10. State various methods of determining the center of gravity.

11. Define equilibrium. Describe the three kinds of equilibrium.

12. What is stability? How is it measured? Give examples of high and low stability.

13. A body weighs 50 lb. at the earth's surface. How much will it weigh 5,000 miles above the surface?

14. A body weighs 50 lb. 10,000 ft. above the earth's surface. How much will it weigh at the surface?

15. A body weighs 100 lb. at the earth's surface. How high above the surface would it have to be in order to weigh 40 lb.?

16. A body 4 × 3 × 2 ft. weighs 200 lb. Compute its stability as it rests on each face.

CHAPTER V

FORCES

38. Force.—Before attempting a definition of *force*, let us examine the various *effects* which a force may produce. It is evident, from common experience, that a force may:

(*a*) Cause a body at rest to move,
(*b*) Bring a moving body to rest,
(*c*) Cause a body to increase or decrease its speed,
(*d*) Alter the course of a moving body,
(*e*) Cause a change in the shape of the body by stretching, compressing, bending, twisting it, etc,
(*f*) Cause certain combinations of the above effects.

No better or simpler illustrations of the effects of forces can be had than from our national game,—baseball. Let us assume that the teams are on the field and that the batter is "up." The ball, which is at rest (zero motion), will have velocity imparted to it as the pitcher makes his delivery. If the batter swings and misses, the ball will settle to rest in the catcher's mitt. In this case, the ball is stopped both by the muscular effort of the catcher and the inertia of the mitt. On the second delivery, the batter may drive a ball served to him slowly with such tremendous velocity that it will clear the stand or, if the delivery is fast, bunt it slowly into the infield, in either case changing both the amount and direction of the original motion. In addition, the impact of the ball and bat tends to change the shape of the ball.

From the above discussion, it is evident that *a force is anything tending to cause a change in the amount or direction of the motion possessed by a body or a change in the shape of the body itself.*

39. Action and Reaction.—Whenever one body *acts* upon another body, the body acted upon exerts an *equal* and *opposite* effect commonly called a *reaction.* The following illustrations will make clear the difference between action and reaction.

1. Suppose we have a book weighing 2 lb. resting upon a table as in Fig. 24. It will be seen that gravity pulls the book against the table with a force of 2 lb. It will be seen, also, that the table pushes up against the book with a force of 2 lb.; otherwise the book would move down through the table. Gravity is the action, and the upward force exerted by the table is the reaction.

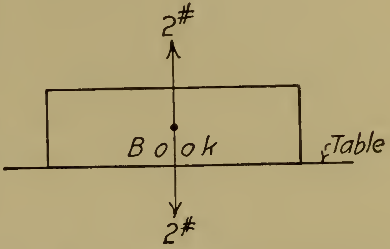

Fig. 24.—Action and reaction.

2. A horse is tied to a post by means of a halter. If the horse pulls horizontally with a force of 200 lb., the post must exert a force of 200 lb. in the opposite direction. The horse causes the action and the post the reaction.

3. Two boys are pulling at the opposite ends of a rope. If one boy exerts a force of 40 lb., the other boy must exert a force of 40 lb. in the opposite direction. In this case, either boy may be considered as causing the action.

4. An automobile is being towed over a level stretch at uniform speed. The force exerted by the tow rope is the action and friction is the reaction.

5. If the automobile in (4) is being towed at increasing speed, the force exerted by the tow line is the action, and friction plus inertia is the reaction.

6. If the automobile in (5) is being towed up an incline, the force exerted by the tow line is the action; and friction plus inertia plus the the effect of gravity is the reaction.

40. Measurement of a Force.—We have seen that a force tends to change the amount or direction of the motion possessed by a body or effect a change in the shape of the body. It will be clear, then, that the amount of change produced will determine the magnitude of the force.

A force may be determined in magnitude:

(*a*) By the velocity it will impart to a given body in a given time.

(*b*) By the amount of change of shape that it will cause a body to undergo.

41. Graphical Representation of Forces.—In order to represent a force graphically, three factors must be considered:

(1) the magnitude of the force; (2) the direction in which the force acts; and (3) the point at which the force is applied to the body. This is readily done, in a quantitative way, by the use of an arrow drawn to a suitable scale.

For example, suppose a body *B* (Fig. 25) to be acted upon by a pulling force of 100 lb. (F_1) acting west and another pulling force of 200 lb. (F_2) acting east. Assuming that 1 in. = 200 lb., it is necessary only to draw a line ½ in. long due west from *B*, and another line 1 in. long due east from *B*

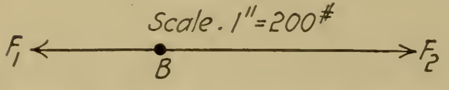

FIG. 25.—Forces represented graphically.

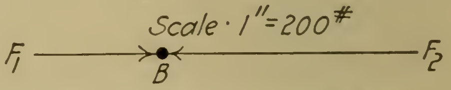

FIG. 26.—Forces represented graphically.

The arrows show the direction of the forces, also that the body *B* is being subjected to *tension*, tending to pull apart the particles of which the body is composed.

In case F_1 and F_2 act as pushing forces, the arrows would be placed as shown in Fig. 26. The body *B* is now under compression, tending to crowd the particles of which it is composed closer together.

42. Moment of a Force.—We have seen that forces have a tendency to produce motion. Under certain conditions, the motion may take the form of rotation about a fixed point (*fulcrum* or *axis of rotation*).

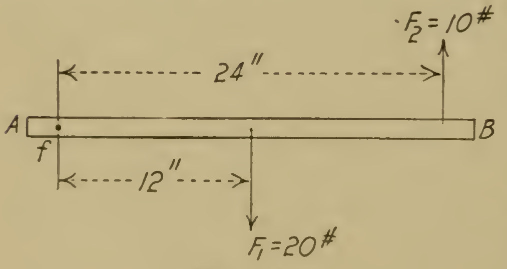

FIG. 27.

For example, suppose *AB* (Fig. 27) to be a rigid bar without weight, arranged to turn about a pin at the fulcrum (*f*) and acted upon by the forces F_1 and F_2. It is evident that F_1 tends to produce a clockwise rotation and F_2 a counter-clockwise rotation. Each force, then, tends to set up an opposite rotation about *f*.

The measure of the tendency of a force to produce rotation about a given point is called the moment of that force.

Referring again to Fig. 27:

The moment of $F_1 = 20 \times 12 = 240$ pound-inches.

The moment of $F_2 = 10 \times 24 = 240$ pound-inches.

The rotative effect of each force is the same and the bar *AB* will be at rest. Thus a small force with a long moment arm may produce the same results as a large force with a small moment arm.

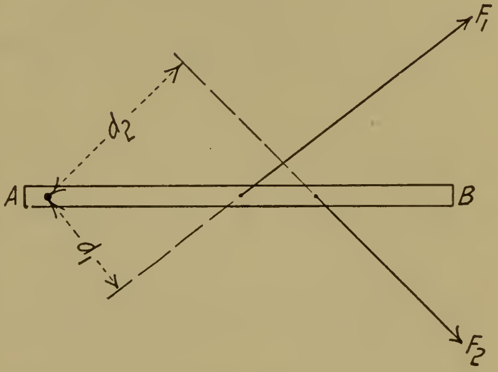

Fig. 28.

The moment arm of a force is the perpendicular distance from the line in which the force acts to the fulcrum or point of rotation. The Moment[1] of a Force = the Force × the Moment Arm.

In the case of forces acting at an angle, it is necessary to find the moment arm as shown in Fig. 28. Thus the moment arms of F_1 and F_2 are d_1 and d_2 respectively. A determination of the perpendicular distances often necessitates an extension of the force lines. The extensions should always be dotted lines.

Questions and Problems

1. State the various effects which a force may produce.
2. From your own observations, give practical illustrations of the above.
3. Define force. How may a force be represented graphically?
4. Give examples of tension and compression.
5. State two ways by which a force may be measured.
6. Under what conditions will a force produce rotation?
7. What is meant by the moment of a force?
8. Define moment arm; fulcrum; torque.
9. State clearly how you would find the moment of a certain force.
10. Explain why forces never exist singly.
11. Distinguish carefully between action and reaction, giving simple illustrations.
12. Indicate the actions and reactions in the following cases:

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[1] For pulleys, etc., the moment is often called *torque.*

(*a*) A team of horses towing an automobile on the level.

(*b*) A team of horses towing an automobile up a hill.

(*c*) A team of horses towing an automobile up a hill at increasing speed.

(*d*) Firing a gun.

(*e*) A train coasting into a station.

(*f*) A Hudson River steamboat proceeding north at increasing speed; the same boat going down stream at increasing speed.

(*g*) The roof truss (Fig. 63). Use selected points.

CHAPTER VI

MOTION

43. Motion.—Motion is the *change of position* which a body undergoes with reference to some given *point* or *object* and is always brought about by the application of *force*. Rest means a *permanence of position* with reference to some given point or object. Rest is simply a statement of zero velocity, indicating *lack of change of position* with respect to some point or object.

44. Absolute and Relative Motion.—If we wish a highly scientific statement of motion, we must record the successive changes with respect to some ideal point fixed in space. The motion is then *absolute*.

Ordinarily we think of motion with respect to some nearby object (or objects), in which case the motion is *relative*. In defining the speed of an automobile as 30 m.p.h., the ground is taken as a basis of comparison. Actually both the ground and automobile are in motion on account of the earth's rotation and revolution. Thirty m.p.h. simply means that the speed of the automobile in a given direction exceeds that of the earth in the same direction by 30 miles per hour.

Two express trains, travelling at the rate of 60 m.p.h. in the same direction, have a velocity of zero with respect to each other, and a velocity of 60 m.p.h. each with respect to the earth. The same trains, travelling in opposite directions, have a velocity of 60 m.p.h. with respect to the earth and a velocity of 120 m.p.h. with respect to each other.

A man walking forward in a submerging submarine will have various velocities. He will have a velocity with respect to the land, the water, members of the crew, a torpedo just discharged, etc. It is evident, from the foregoing illustrations, that *for practical purposes all motion is relative;* that is, to define the motion of any body, we must refer it to some nearby body as a basis of comparison.

45. Translatory and Rotary Motion.—In order to have *translatory motion* (*motion of translation*), every particle of which a rigid body is composed must have the same linear velocity at each instant as every other particle. It is evident that each particle will travel in a path either parallel to, or coincident with, that of its neighbor. Furthermore, a straight line connecting any two particles will always keep the same direction. Translatory motion may be *curvilinear* (in a curved line) or *rectilinear* (in a straight line). It may also be *uniform* or *variable.* The motion of an engine piston and a pile driver are good examples of rectilinear-translatory motion. A body projected horizontally from a tower without rotation is a good example of curvilinear-translatory motion.

In *rotary motion* (*motion of rotation*), each particle travels at the same angular velocity as the other, but particles farthest from the axis of rotation will possess the greatest linear velocity. It will be seen that each particle will describe a course either parallel to, or coincident with, that of its neighbor; and that only particles equally distant from the axis will travel with the same linear velocity. The motion of a flywheel and an airplane propeller are common examples.

46. Accelerated Motion.—*Acceleration is the rate at which the velocity of a body is increased or decreased.* For example, if an automobile, starting from rest, increases its velocity 2 ft. every second for 10 consecutive seconds, the acceleration is then 2 ft. per second per second (written 2 ft./sec.^{2}). This simply means that the velocity increases at the rate of 2 ft./sec. during every second. The same acceleration may be expressed as 120 ft./min./sec. In the above illustration the acceleration is *uniform* and *positive,* that is to say, the change of velocity is constant and causes an increase in the speed of the automobile. When a body is so acted upon by an acceleration that a decrease in velocity results, the acceleration is *negative.* For example, if a projectile is shot vertically upward with a velocity say of 1,000 ft. per sec., the acceleration of gravity causes the body to lose 32.16 ft. per second during each second and will eventually stop its flight. The acceleration of gravity is negative for rising bodies and positive for falling bodies.

47. Speed and Velocity.—Speed is the *rate at which a body moves.* It concerns itself with *displacement* and *time* only, the direction not being taken into consideration. An express train travelling at the rate of 60 m.p.h. is said to have a speed of 60 m.p.h. In discussing the velocity of the train, we must include another element,—*direction.* If the train in proceeding due north, it has then a velocity of 60 m.p.h. due north.

In case the velocity of a body is *variable,* it is expressed as if the velocity of the body were to become uniform at the particular instant. This is called *instantaneous velocity.* A body with an instantaneous velocity of 10 m.p.h. will not necessarily cover 10 miles in an hour. The distance covered will depend on the average velocity for the given time.

The *velocity* (v) at the end of any second for a uniformly accelerated body starting from rest is equal to the acceleration (a) multiplied by the time (t). Thus the velocity of a freely falling body at the end of the first 5 seconds will be 32.16 × 5 or 160.80 ft./sec.

$$v = at$$

If a body is uniformly accelerated, the *average velocity* ($v\ av.$) may be found by adding the initial velocity ($v\ in.$) to the final velocity ($v\ fin.$) and dividing by 2. To illustrate, suppose a body falls from a state of rest. Since the acceleration of gravity is 32.16 ft./sec.^{2}, the velocity at the end of 3 seconds will be 96.48 ft./sec. The average velocity for the 3 seconds will be $(0+96.48)/2$ or 48.24 ft./sec.

$$v\ av. = \frac{v\ in. + v\ fin.}{2}$$

In case the velocity of a body is uniform, the *total distance* (S) covered in a number of seconds is equal to the uniform velocity ($v\ un.$) multiplied by the time (t) in seconds. For example, if a body has a uniform velocity of 1,000 ft./sec., in 10 seconds it will travel, 1,000 × 10 or 10,000 ft.

$$S = v\ un. \times t$$

If the velocity of a body is uniformly accelerated, the *total distance* (S) covered in a number of seconds (t) will equal the average velocity ($v\ av.$) multiplied by the time. Accordingly, a freely falling body will cover 144.72 ft. during the first 3 seconds of fall. The average velocity for the 3 seconds will be $(0 + 96.48)/2$ or 48.24 ft./sec. $48.24 \times 3 = 144.72$ ft.

$$S = v\ av. \times t$$

48. Momentum.—*The quantity of motion possessed by a moving body is called momentum.* Momentum is measured by the product of the *mass* and *velocity* of the body.

$$Momentum = Mv$$

There is no recognized unit of momentum in the English system of measurement. For practical purposes we may assume the unit to be a mass of one pound moving at the rate of 1 ft. per second. For example, a 10,000 ton ship with a speed of 20 ft./sec. is said to have 400,000,000 f.p.s. units of momentum (10,000 × 2,000 × 20).

In the c.g.s. system the unit of momentum is the *bole.* It is the momentum produced when a mass of 1 gram is moving at the rate of 1 cm./sec. The number of boles is equal to the product of the mass in grams and the velocity in centimeters/sec. ($b = Mv$). For example, a 100 Kg. projectile with a velocity of 300 m./sec. will have a momentum of 3,000,000,000 c.g.s. units or 3,000,000,000 boles (100 × 1,000 × 300 × 100).

49. Newton's Laws of Motion.—The following laws were formulated by Sir Isaac Newton. A thorough understanding of these laws is very important.

I. Every body continues in its state of rest or of uniform motion in a straight line, unless compelled to change that state by an impressed force.

II. Change of momentum is proportional to the force acting and takes places in the direction in which the force acts.

III. To every action there is always an equal and opposite reaction.

50. Newton's First Law.—A body is incapable of putting itself in motion. A book, lying on a table, will remain in the same position indefinitely, unless acted upon by some outside force. Likewise, a body in motion will continue to move indefinitely, unless acted upon by some outside force. A thrown baseball tends to continue on forever in a straight line. Were it not for gravity and the retarding effect of the atmosphere, the ball would never come to rest. It is clear from this discussion that Newton's first law is a statement of the *law of inertia.*

51. Newton's Second Law.—It is obvious from Newton's second law that the amount of change of momentum undergone by a body depends on the magnitude of the force acting. Thus we are able to measure a force by the change in momentum it will produce in a given time. The force varies directly as the *change in momentum* and inversely as the *time consumed.*

$$F \alpha Mv / t$$

If the impressed force acts counter to the motion of the body, the momentum will be decreased; if with the motion of the body, the momentum will be increased.

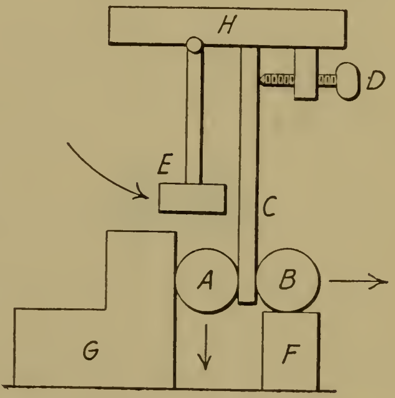


Fig. 29.—*A* and *B* will reach the floor at the same instant.

According to the second law, a cannon ball dropped from a height of 200 ft. will strike the ground at exactly the same moment as another ball shot horizontally from the same height. This is due to the fact that each ball is given the same downward acceleration by gravity. Further, the balls will always keep the same relative position from the ground while in the air. We see also, from the illustration, that the change of momentum is always in the direction in which the force acts. The first ball is acted upon by gravity only and has simply a downward momentum. The second ball is acted upon by the force of the explosion as well as gravity and has both a *horizontal* and *downward* momentum, each change of momentum being independent of the other.

A simple experiment will illustrate the above law. *A* and *B* (Fig. 29, essential details shown only) are two similar steel balls. *B* rests on the support *F* and *A* is held in place by the friction between *C* and *G*. The thumb screw *D* enables proper adjustment of the spring *C* attached at *H*. With the balls *A* and *B* at the same level, the hammer *E* is allowed to fall against *C*. As a result *A* is released and falls to the floor, while *B* is driven out horizontally and describes a parabolic path to the floor. Each ball reaches the floor at the same instant.

52. Newton's Third Law.—Any action between two bodies is mutual. In jumping from a boat to the shore, the boat tends to gain an equal and opposite momentum to that of the person jumping. A perfectly elastic ball thrown against a brick wall tends to bound back with the same velocity with which it struck the wall. In firing big guns it is necessary to absorb the reaction by means of recoil springs, otherwise the guns might break loose from their foundations. In case of an inelastic body like putty, the reaction will have a flattening effect.

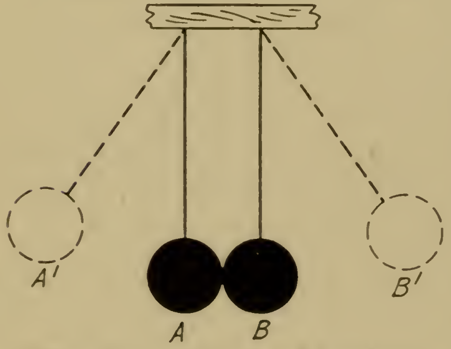


FIG. 30.—Action and reaction.

In Fig. 30, *A* and *B* are two highly elastic steel balls. If *B* is displaced to the position of *B′* and allowed to fall against *A*, the impact will cause *A* to undergo an equal displacement in the opposite direction as shown in *A′*. In case *A* is held fast, *B* will bound back to *B′*.

53. Graphical Representation of Motion.—A single force, if of sufficient magnitude, will cause a body to move in a straight line. The motion is fully defined when the following are given: (*a*) *the amount of the motion;* (*b*) *the direction of the* *motion; (c) the former position of the body.* To represent the motion of a body graphically, it is only necessary to draw a straight line of suitable length, with an arrow head pointing in the proper direction. Such a line is called a *vector* or *vector line.* To illustrate, suppose we wish to represent the motion of a body travelling east with a velocity of 10 ft./sec. First we adopt some convenient scale, such as 1 in. = 2 ft./sec. Then we draw a line 5 in. long, using an east and west axis. At the east extremity we draw an arrow head pointing due east. In constructing vector lines, the scale used should be indicated clearly.

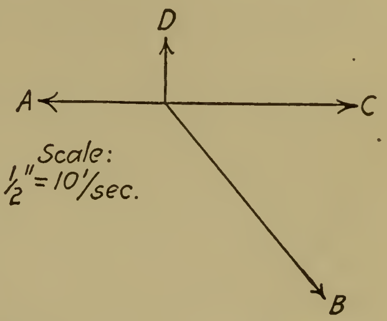


Fig. 31.—Velocities represented graphically.

In Fig. 31, there are four vector lines indicating velocities from a common point in four different directions. Since the scale used is ½ in. = 10 ft./sec., it is evident, by a measurement of the lines, that *A* has a velocity of 10 ft./sec. due west; *B* a velocity of 20 ft./sec. due southeast; *C* a velocity of 15 ft./sec. due east; and *D* a velocity of 5 ft./sec. due north.

54. Velocity of Rotation.—In expressing the velocity of a rotating body two methods are in use: (*a*) the *length of arc* described by a selected point in a given time; or (*b*) the *angular* change that the point makes from the axis of rotation in a given time. The point selected is considered to be on the rim of the rotating body. In the first case, it is clear that the arc described will be *in proportion* to the distance to the center of rotation; while, in the second case, the angular velocity will be *independent* of the distance from the center.

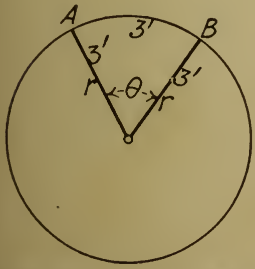


Fig. 32.—Angle θ is a radian.

Angular velocity may be expressed as *revolutions per minute* (*r.p.m.*) or *degrees per minute* (*d.p.m.*). In the latter case a unit called a *radian* is used. *A radian is an angle of such* *magnitude that the arc which it intercepts on the circumference is exactly equal to the radius of the circle.*

In Fig. 32, angle θ is a radian since the arc AB is just equal in length to the radius r. As the circumference of a circle equals $2\pi r$, it will be seen that in every circumference there are 2π radians ($2\pi r/r$). Also, since there are 360° in a circle it is evident that a radian is equal to 57.3° ($360/2\pi$). Further *the linear velocity of any point may be determined by multiplying the velocity in radians by the distance from that point to the axis of rotation.* If the angular velocity in Fig. 32 is 10 radians/sec., the linear velocity of any point in the circumference will be 30 ft./sec. (10×3).

Questions and Problems

1. Define (*a*) motion; (*b*) rest. How is a body set in motion? Brought to rest?

2. What is (*a*) absolute motion? (*b*) relative motion? Discuss fully.

3. State the difference between speed and velocity and give an example of each.

4. What is variable velocity? Average velocity? Instantaneous velocity? How would you compute the actual distance passed over in a given time by a body whose velocity is variable? Uniformly accelerated?

5. Define and give an example of (*a*) translatory motion; (*b*) rotary motion. Give an instance of a combination of the two.

6. What is acceleration? Uniform acceleration? Variable acceleration? Positive acceleration? Negative acceleration? Illustrate in each case.

7. What is the mathematical relation between velocity, uniform acceleration and the time? Between total distance passed over, average velocity and the time? Between total distance passed over, uniform velocity and the time?

8. Define momentum. What is the formula for momentum?

9. What is the unit of momentum in the f.p.s. system? The c.g.s. system?

10. State and discuss Newton's first law of motion.

11. State and discuss Newton's second law of motion. What general relation is there between momentum, the force producing it and the time? Describe an experiment to illustrate the second law.

12. State and discuss Newton's third law of motion. Give an experiment to show that action and reaction are equal and opposite in direction.

13. What is a vector or vector line? How may the velocity of a body be represented graphically? Give an example.

14. In how many different ways may the velocity of a rotating body be expressed? What is a radian? How many radians in a circumference? How many degrees in a radian? How may the velocity in radians be reduced to linear velocity?

15. Represent graphically a velocity of 100 ft./sec. acting north.

16. Represent graphically velocities of 100 ft./sec., 80 ft./sec., 70 ft./sec. and 65 ft./sec. acting north, east, south and southwest respectively from the same point.

17. An automobile flywheel is making 1,200 r.p.m. Express the velocity in degrees/min.; in radians/min. If the wheel is 1½ ft. in diameter, what is the linear velocity of a point on the circumference?

18. A locomotive is turned around (front to back) on a turntable in 4 minutes. Express the angular velocity in radians/sec. In degrees/hour.

19. Two gyroscopes are running with velocities of 2,000 r.p.m. and 200 radians/sec. respectively. Which has the greater velocity? By how much? Give answer in radians.

20. A circular saw is running at the rate of 12,000 radians/sec. The distance between the extremities of two diametrically opposed teeth is 18 in. How far does the point of a tooth travel per second? How many r.p.m. does the saw make?

21. Express the velocity of a point on the equator in r.p.m. In ft./sec. In radians/sec. Assume circumference of the earth to be 25,000 mi.

22. A grinder is running at the rate of 3,500 r.p.m. By how much does this vary from a speed of 200 radians/sec? Give answer in r.p.m.

CHAPTER VII

COMPOSITION OF FORCES AND VELOCITIES

55. Resultant of Two or More Forces.—Whenever two or more forces in the same plane are applied to a body at a fixed point, these forces may be replaced by a single force which will have the same effect on the body as the joint action of the original forces. This single force is known as the *resultant* force. The process of determining the resultant of two or more concurrent forces is known as the *composition of forces.* The separate forces are called *components.*

For the sake of simplicity, let us assume that we are dealing with two forces only. It is evident that the two forces may act (1) in the same straight line in the same direction; (2) in the same straight line in opposite directions; (3) or at an angle with each other.

1. If two forces act in the same straight line and in the same direction, it is evident that the resultant is equal to their *sum.* For example, if two forces of 10 and 20 lb. each are applied to a body and act due east, they may be replaced by a single or resultant force of 30 lb. applied at the same point and acting due east.

2. If two forces act in the same straight line and in opposite directions, it is evident that the resultant is equal to their *difference.* For example, if two forces of 10 and 20 lb. act east and west respectively, they may be replaced by a single or resultant force of 10 lb. applied at the same point and acting due west.

3. If two forces act upon a body at an angle, the resultant is equal neither to their sum or difference, but must be found by means of the *parallelogram law.* This will be described in the following paragraph.

56. Parallelogram of Forces.—Suppose it is desired to find the resultant of two forces acting at an angle and represented graphically as in Fig. 33. Using the force lines F_1 and F_2 as adjacent sides, a parallelogram is constructed and a diagonal from the point of application is drawn. The diagonal represents the resultant both in amount and direction, according to the scale used. Thus the single force R will have the same effect as the joint action of F_1 and F_2.

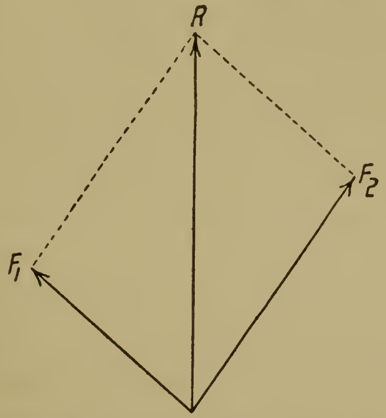


FIG. 33.—The resultant R has the same effect as the joint action of F_1 and F_2.

57. Experimental Verification of the Parallelogram Law.—The following experiment was performed by the author as a classroom demonstration, the purpose being to prove that the parallelogram law is true. A weight of 19.4 lb. was suspended

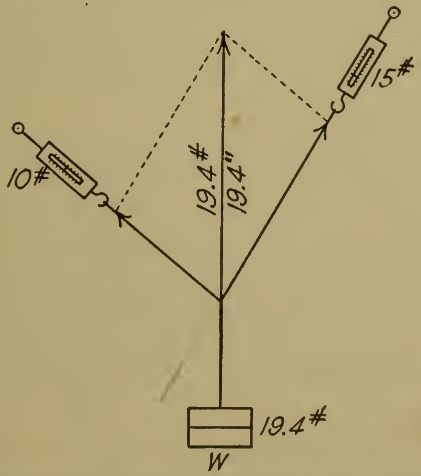


FIG. 34.—Apparatus for verifying the parallelogram law.

before the blackboard as shown in Fig. 34, care being taken that there was no friction between the weight and the board. The balance readings recorded were 10 and 15 lb. We now have three concurrent forces in equilibrium. It is evident that the *combined effect* of the upward forces is just sufficient to hold up the suspended weight. In other words, the *resultant* of the two upward forces must be *equal* and *opposite in direction* to W. If this is confirmed by the parallelogram law, we may assume the law to be correct.

The three forces were located on the blackboard by placing a rectangular block along the cords and marking with a sharp piece of chalk. The forces (10 and 15 lb.) were represented graphically, the scale used being 1 in. = 1 lb. The parallelogram was completed and the diagonal drawn. The diagonal measured 19.4 in. According to the scale assumed, 19.4 in. represents 19.4 lb. Since the resultant is found to be equal and opposite in direction to W, we may be certain that the parallelogram law is correct. W is here known as the *equilibrant. The equilibrant is always equal in magnitude and opposite in direction to the resultant.*

58. Composition of Velocities.—Since velocities are brought about by the application of forces, it logically follows that the resultant of two velocities may be determined in the same way as the resultant of two forces. It is thought that no discussion will be necessary to enable the student to solve such simple problems as will be given him.

59. Forces and Velocities Exceeding Two in Number.—In case we have to deal with more than two forces acting at an angle, it is necessary to find the resultant of two of them; then to find the resultant of the resultant just found and the next force. This process is continued until each force has been used. The same method is followed in case of more than two velocities.

60. Directions for Graphical Work.—Accurate work is essential in solving problems by the graphical method. Carelessness is inexcusable and results in a waste of time. The following directions and suggestions should be studied carefully.

1. Graphical diagrams should be drawn in pencil. A fairly hard pencil with a sharp point gives the best results.
2. If the paper is of good grade, the lines may be inked over with india ink. Never use ordinary ink.
3. Be sure that the ruler used has a straight edge.
4. Use a compass in completing the parallelogram.
5. Be sure that all angles are correctly represented.
6. Avoid small parallelograms. It is suggested that one half of an ordinary sheet of paper be allowed. This will tend to increase accuracy.
7. Use squared paper if possible.
8. Label each diagram fully, being sure to indicate the scale used.

Questions and Problems

1. What is meant by the composition of forces?

2. Define (*a*) resultant; (*b*) component; (*c*) equilibrant.

3. How would you find the resultant of several forces acting at an angle and attached at the same point?

4. Find the resultant of the forces given below:

(*a*) 10 lb. and 30 lb.; angle between = 25°.
(*b*) 100 lb. and 60 lb.; angle between = 40°.
(*c*) 24 Kg. and 36 Kg.; angle between = 90°.
(*d*) 100 lb. and 200 lb.; angle between = 125°.
(*e*) 200 lb. and 112 lb.; angle between = 140°.
(*f*) 500 g. and 590 g.; angle between = 100°.

5. A motor boat has a velocity of 10 m.p.h upstream (north). The wind gives the boat a velocity of 2 m.p.h. to the east. Find the direction in which the boat goes and the actual distance covered in one hour.

6. An automobile is travelling north at a rate of 40 m.p.h. The wind is blowing from the west at the rate of 15 m.p.h. What is the resultant velocity of the wind? From what direction does the wind seem to come?

7. In what direction would a weather vane point in problem 6, if mounted on the radiator of the car?

8. A balloon rises at the rate of 25 ft. per second. It is blown east at the rate of 5 ft. per second. Find the rate and direction of motion.

CHAPTER VIII

RESOLUTION OF FORCES AND VELOCITIES

61. Resolution of Forces and Velocities.—It has been shown, in the previous chapter, that we may replace two or more forces (or velocities) applied at the same point and in the same plane, by a single force (or velocity) having the same effect. We shall now see that it is possible to replace a single force (or velocity) with two or more components having the same joint effect as the original force (or velocity). *The process of replacing a single force (or velocity) with two or more forces (or velocities) having the same joint effect as the original force (or velocity), is called the resolution of forces (or velocities).* Resolution is the opposite of composition. Problems dealing with resolution may be solved by means of the parallelogram law.

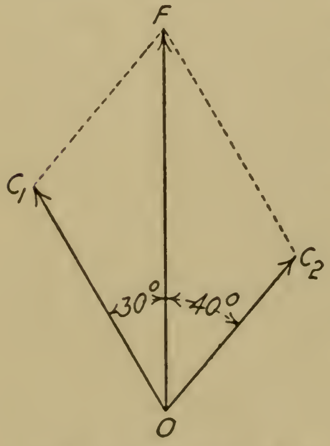


Fig. 35.—F may be replaced by its components C_1 and C_2.

Suppose we wish to resolve a force (F) into two components (C_1 and C_2) at angles of 30° and 40° respectively with the force. First F is represented graphically, both in amount and direction, as shown in Fig. 35. C_1 and C_2 are drawn from O of indefinite length and at the proper angles. The components are now represented in direction, but not in magnitude. A parallelogram is next formed with F as the diagonal. Thus the components (C_1 and C_2) are defined in length. According to the scale assumed for F, they are now determined in amount. C_1 and C_2, acting jointly, will have exactly the same effect at O as F.

In case the components are known in magnitude, but not in direction, a pair of compasses will be necessary to complete the geometrical construction.

If the angles are decreased, the components will decrease; if the angles are increased, the components will increase.

62. Vertical and Horizontal Components.—Frequently it is necessary to resolve a given force or velocity into *rectangular* components. Figure 36 represents a force (F) resolved graphically into vertical and horizontal components (V and H). The vertical component (V) represents the effective value of F vertically and the horizontal component (H) represents the effective value of F horizontally. Thus we are able to determine both the lifting effect and the horizontal pull produced by F.

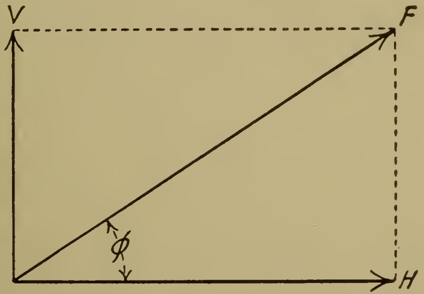


FIG. 36.—Rectangular components.

63. Value of Squared Paper.—Graphical results in the resolution of forces and velocities are facilitated by the use of squared paper. For example, suppose (Fig. 37) we have a force of 120 lb. acting ϕ degrees to the horizontal. If the

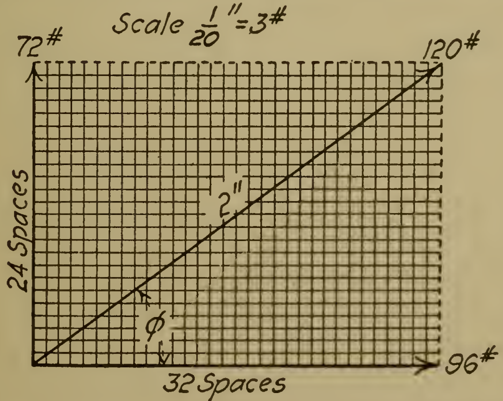


FIG. 37.—Resolution by means of squared paper.

paper is ruled in $\frac{1}{20}$ in. squares, then $\frac{1}{20}$ in. = 3 lb. is a good working scale. Thus to represent 120 lb., we draw a line 2 in. long. The *rectangular* components may now be determined in value directly, a rule being unnecessary. By inspection we see that V is 24 spaces long and $= 24 \times 3 = 72$ lb. in magnitude. H is found to be 32 spaces long and $= 32 \times 3 = 96$ lb. in magnitude.

64. Resolution by the Trigonometrical Method.—A force or velocity may readily be resolved into *vertical* and *horizontal* components by the use of simple trigonometric functions. Referring to Fig. 38, it is evident that $\cos 30° = H/F$, or $H = F \cos 30°$, $H = 60 \times .866 = 51.96$ lb. Also $\cos 60° = V/F$, or $V = F \cos 60°$, $V = 60 \times .500 = 30$ lb.

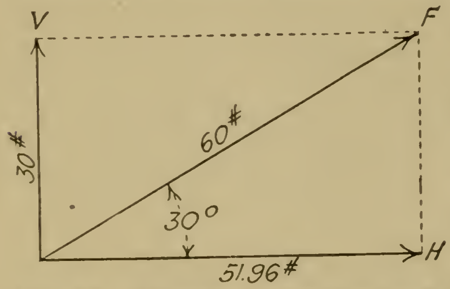


FIG. 38.—Rectangular components determined trigonometrically.

65. Composition of Forces by Resolution into Vertical and Horizontal Components.—If several forces act in the same plane and are applied at the same point, their resultant may be found by resolving all the forces not vertical or horizontal into their vertical and horizontal components. Since the forces are now all vertical or horizontal, by proper additions and subtractions we may combine them into one vertical and one horizontal force. The resultant of the last-mentioned forces will given the resultant of the original forces both in magnitude and direction.

Questions and Problems

(Solve problems graphically unless otherwise instructed)

1. Explain what is meant by resolution of forces.

2. What are rectangular components?

3. How would you find the resultant of several forces applied at the same point and in the same plane?

4. Resolve a force of 20 Kg. into two components at angles of 15° and 25° with the force.

5. Resolve a force of 200 lb. into two components such that one component will be a force of 120 lb. acting at an angle of 30° with the 200 lb. force. Give also the angle at which the second component acts.

6. Resolve a force of 40 lb. into two components of 20 lb. and 30 lb. each and find the angle between each component and the original force.

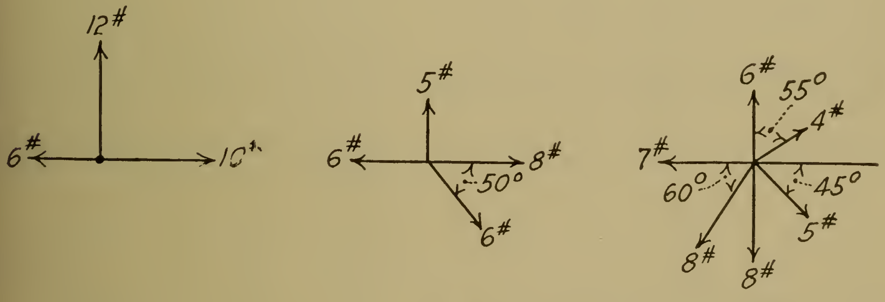
7. Resolve a force of 500 lb. acting at an angle of 35° to the horizontal into its vertical and horizontal components. Solve with squared paper.

8. Repeat Problem 7, using a trigonometrical solution.

9. Repeat as in Problems 7 and 8 for a force of 1,000 lb. acting at an angle of 60° with the horizontal.

10. A motor boat has a velocity of 15 m.p.h. due north in still water. In one hour, due to a west wind, it actually travels 18 miles due northeast. Find the velocity imparted to the boat by the wind.

11. A tug boat is towing a scow at an angle of 5° with the axis of the scow. If the tension in the tow line is 300 lb., what force is moving the scow ahead and what force is tending to move the scow to the side?



(1) (2) (3)

Fig. 39.

12. Using the method of resolution into rectangular components, determine the resultant of the sets of forces in Fig. 39.

13. Resolve a force of 300 Kg. into two components acting at an angle of 80° with each other, such that one force shall be three times the other.

14. What force will be necessary to keep a 100 lb. ball on an inclined plane 10 ft. long and 3 ft. high? Assume the supporting force to act parallel to the plane and at the center of the ball.

CHAPTER IX

EQUILIBRIUM OF CONCURRENT FORCES

66. Concurrent Forces in Equilibrium.—Forces applied at the same point, or passing through the same point if extended, are called concurrent forces. Concurrent forces will be in equilibrium (of rest or motion) when the opposite vertical forces are balanced and when the opposite horizontal forces are balanced. Stated differently, *a body acted upon by concurrent forces will be in equilibrium, when the resultant of all the forces acting is zero.* For example, the body B (Fig. 40) is at rest. It is evident, then, that:

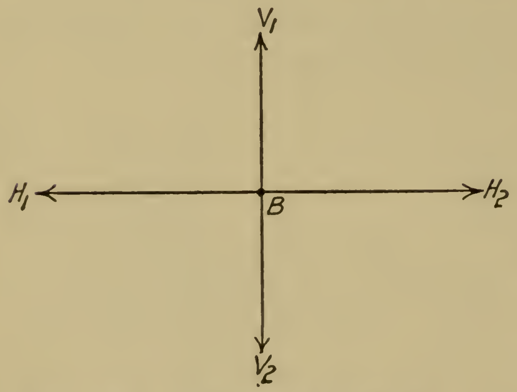


Fig. 40.—Concurrent forces in equilibrium.

$$V_1 = V_2 \text{ and } H_1 = H_2$$

A body acted upon by a single force or by unbalanced forces can never be in equilibrium. In case the forces are not vertical or horizontal, the body acted upon will be in equilibrium if the resultant of the vertical components is zero and the resultant of the horizontal components is zero.

Another case of equilibrium is illustrated in Fig. 41. A body (B) weighing 125 lb. is being moved at a uniform velocity along the surface S–$S1$ by a force of 50 lb. acting at an angle of 25° to the horizontal. Suppose we wish to find the force of friction ($Fr.$) and the perpendicular pressure (P) between the body and the surface. Referring to the "free body" diagram (Fig. 42), it is evident, since the body is in equilibrium, that:

(1) $H = Fr.$ and (2) $V + P = G.$

Since $H = 50 \cos 25°$, and $V = 50 \cos 65°$, it follows that: (1) $50 \cos 25° = Fr.$, and $Fr. = 50 \times .906 = 45.3$ lb.,

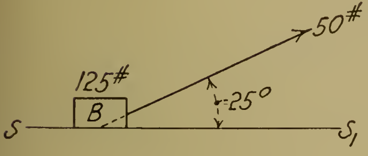


FIG. 41.

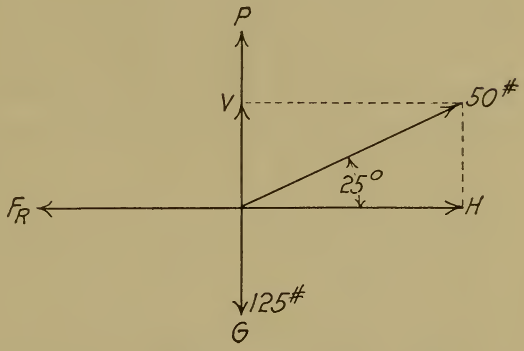


FIG. 42.—Force diagram for Fig. 41.

(2) $50 \cos 65° + P = 125$, and $P = 125 - (50 \times .423) = 103.85$ lb.

67. Triangle of Forces.—If three concurrent forces in the same plane are in equilibrium, they may be represented in *amount* and *direction* by the *sides of a triangle.*

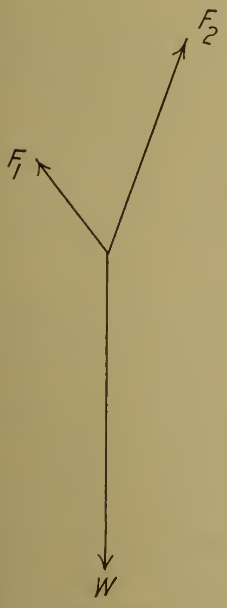


FIG. 43.

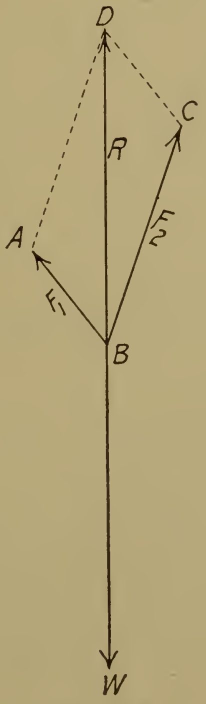


FIG. 44.

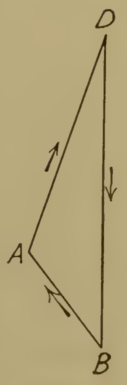


FIG. 45.

Suppose F_1, F_2 and W (Fig. 43) to be in equilibrium. Then as shown in Fig. 44, W is equal to R, the resultant of F_1 and F_2. Still referring to Fig. 44, it is evident that F_1, F_2 and W are proportional respectively to the sides of the triangle ABD, since: (1) F_1 is proportional to BA; (2) F_2 is proportional to BC and therefore to AD; (3) $W = R$ and is therefore proportional to BD, but opposite in direction. Hence the original forces, F_1, F_2 and W are represented both in amount and direction by the sides of the triangle BA, AD and DB, as shown in Fig. 45.

68. Concurrent Forces Applied at Different Points.—Concurrent forces may be applied to a body at the same point or they may be applied at different points. In the latter case, the force lines will meet at a common point if extended.

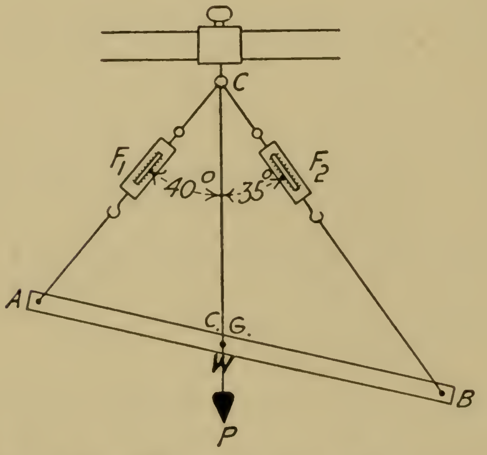


FIG. 46.—Weight of bar A-B is equal to the resultant of F_1 and F_2.

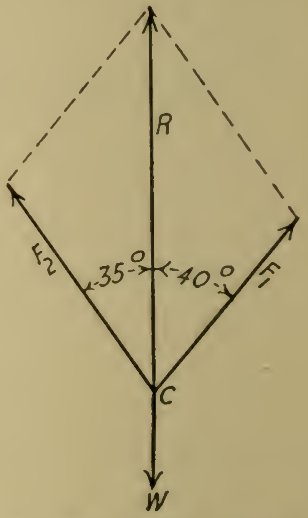


FIG. 47.—Force diagram for Fig. 46.

For example, AB (Fig. 46) is a rigid, uniform bar weighing W lb. and supported by cords and balances as shown. The weight (W) of the bar acts vertically downward at the center of gravity ($C.G.$). W is balanced by the tensions (F_1 and F_2) of the supporting cords. It is clear, since the bar is in equilibrium, that W is numerically the same as the resultant of F_1 and F_2. The plumb line (P), suspended at C, determines the direction of W and will always pass through the center of gravity. If F_1 and F_2 are known, W may be determined;

if W is known, F_1 and F_2 may be determined. The force diagram for Fig. 46 is shown in Fig. 47. F_1 and F_2 (balance readings) are drawn to scale at the proper angle and a parallelogram formed. The resultant (R) is found, using the same scale, and will check with the weight of the bar.

In case the supporting cords diverge, as in Fig. 48, the solution is similar to the one just described. W is numerically the same as the resultant (R) of F_1 and F_2. The dotted parallelogram lines will always intersect along the plumb line (P). Figure 48 is a combined picture and force diagram. In case W is known and it is desired to find F_1 and F_2, the force diagram will be the same, the only difference being that W is drawn to scale, the parallelogram completed, and F_1 and F_2 computed. The computed values should check with the balance readings.

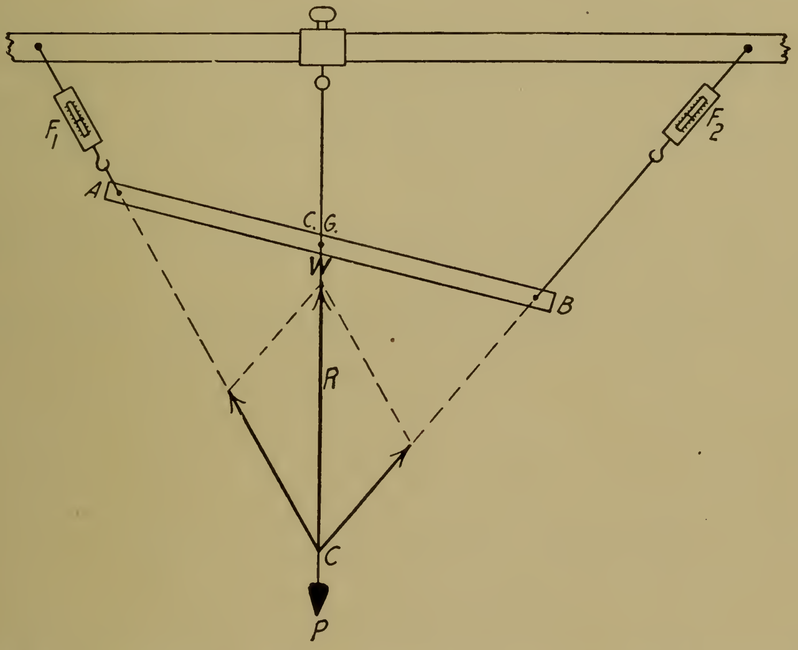


FIG. 48.—Weight of bar A-B is equal to the resultant of F_1 and F_2.

Questions and Problems

1. What are concurrent forces?
2. Under what conditions will concurrent forces produce equilibrium?

3. What is meant by the triangle of forces? Explain fully, using diagram.

4. Describe a typical experiment involving concurrent forces applied at separate points.

5. Find the amount and direction of a force that will produce equilibrium with two forces of 30 and 50 g. acting at an angle of 40° with each other.

6. A block weighing 5 lb. is being pulled uniformly along a surface by a horizontal force of 1 lb. Show by diagram the actions and reactions.

7. A body weighing 50 lb. is being pulled uniformly by a force of 12 lb. acting at an angle of 15° to the horizontal (See Fig. 41). Find the perpendicular reaction of the surface and the horizontal pull.

8. A picture weighing 10 Kg. is suspended by two cords of equal length acting at an angle of 50° with each other. Find tension in the cords.

9. A wire AB 30 ft. long is fastened at either end. If a man weighing 160 lb. stands in the middle and the wire is depressed 2 ft., what is the tension at each end?

10. A bar weighing 10 lb. is suspended as in Fig. 46. Find F_1 and F_2.

CHAPTER X

EQUILIBRIUM OF PARALLEL FORCES

69. Tendencies of Parallel Forces.—Figure 49 represents a rigid, weightless body acted upon by parallel forces. Various effects may be produced by the forces, according to their magnitudes and points of application. They may: (*a*) cause an upward displacement of the body *AB*; (*b*) cause a downward displacement of *AB*; (*c*) cause *AB* to rotate; (*d*) cause a simultaneous displacement and rotation.

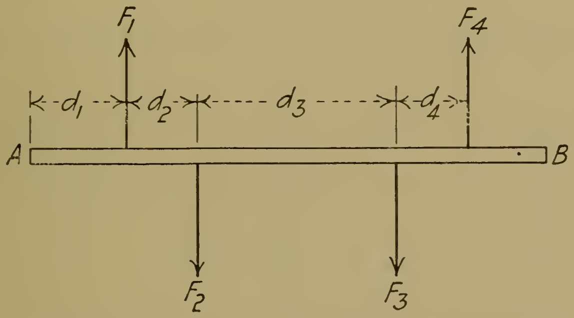


Fig. 49.—Body acted upon by parallel forces.

70. Equilibrium of Parallel Forces.—In order to avoid the effects as stated in the previous paragraph, that is, in order that the body *AB* shall be in equilibrium (at rest), the following conditions must prevail:

1. The sum of the "up" forces must equal the sum of the "down" forces,

$$F_1 + F_4 \text{ must equal } F_2 + F_3$$

2. The sum of the moments tending to produce rotation in one direction must equal the sum of the moments tending to produce rotation in the opposite direction. Assuming any point as the axis of rotation (fulcrum), *e.g.*, point *A*, then,

$$F_2 \times (d_1 + d_2) + F_3 \times (d_1 + d_2 + d_3) \text{ must equal}$$
$$F_1 \times d_1 + F_4 \times (d_1 + d_2 + d_3 + d_4)$$

Summarizing, we may say that a body acted upon by parallel forces will be in equilibrium when:

1. *The sum of the forces acting in one direction equals the sum of the forces acting in the opposite direction;*

2. *The sum of the clockwise moments equals the sum of the counter-clockwise moments.*

71. The Laws of Parallel Forces Proven by Experiment.—The conditions necessary for equilibrium as stated in the previous paragraph may be verified in the laboratory. The following experiment was performed by two students.

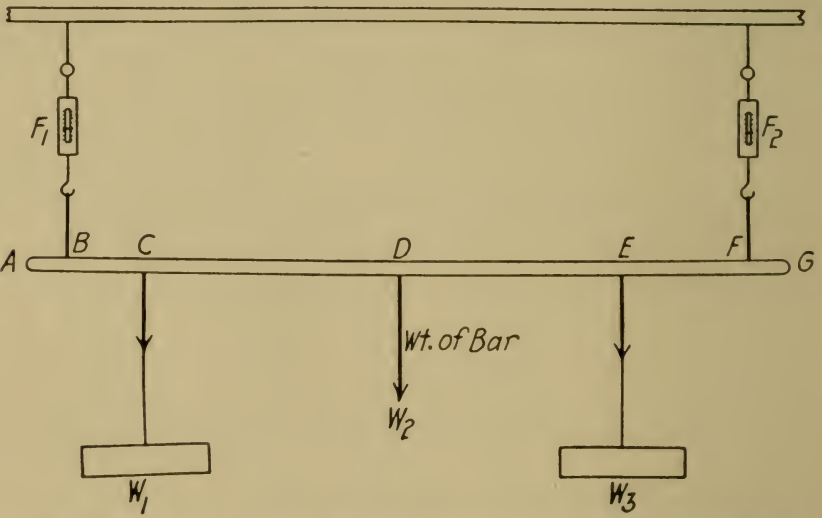


Fig. 50.—Apparatus for studying the laws of parallel forces.

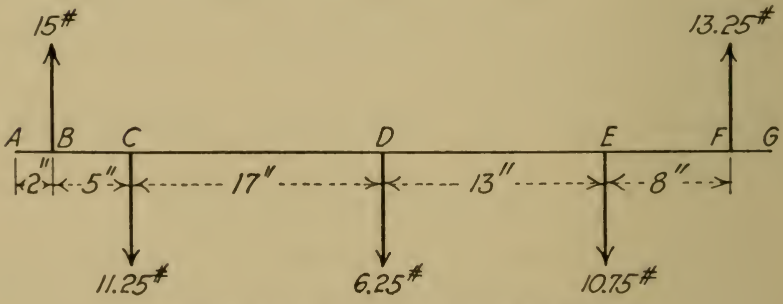


Fig. 51.—Force diagram for Fig. 50.

AG (Fig. 50) is a rigid steel bar weighing 6.25 lb. and supported by two spring balances. Weights of 11.25 lb. and 10.75 lb. were suspended from *C* and *E*. The weight of the bar concentrated at its center of gravity is represented by a force of 6.25 lb. acting downward at *D*. The apparatus was carefully adjusted until *AG* was horizontal and the balances vertical. The balance readings were observed and the distances between the forces measured. A force diagram was then constructed, with the forces and distances clearly labelled (Fig. 51).

The moments of the various forces were determined first about *A* and then about *D*. The results were finally tabulated as shown below.

Forces in lb.			Moments around *A* in lb.-in.		Moments around *D* in lb.-in.	
At	Up	Down	Clockwise	Counter-clockwise	Clockwise	Counter-clockwise
B	15.00	......	......	30.00	330.00	......
C	......	11.25	78.75	......	......	191.25
D	......	6.25	150.00	......	......	......
E	......	10.75	397.75	......	139.75	......
F	13.25	......	......	596.25	......	278.25
Totals...	28.25	28.25	626.50	626.25	469.75	469.50

An examination of the above tabulation shows that the sum of the "up" forces exactly equals the sum of the "down" forces; also that the sum of the clockwise moments is practically the same as the sum of the counter-clockwise moments. The small difference in the moments is due to the fact that it is impossible to measure distances with 100 per cent. accuracy. This experiment verifies the laws of parallel forces as stated in Par. 70.

72. The Resultant and Its Point of Application for a System of Parallel Forces.—Suppose it is desired to replace the system of forces in Fig. 52 by a single force (resultant) having the same effect as the joint action of the separate forces. We must find the magnitude of the force and its point of application. It is evident that the resultant will be equal and opposite in direction to the force needed to cause equilibrium. This force is found as follows:

$$15 + E + 10 = 10 + 20 + 25 + 45,$$
$$E = 75 \text{ lb. resultant force.}$$

To find the point of application, assume A as the point of rotation and take distances from A as in the parentheses.

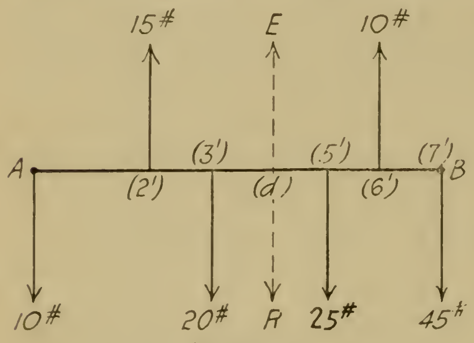


Fig. 52.

From the law of equilibrium of parallel forces we have:

$$15 \times 2 + 75 \times d + 10 \times 6 = 20 \times 3 + 25 \times 5 + 45 \times 7, d = 5.46 \text{ ft. from } A.$$

Hence we find that the resultant of the above forces is a down force of 75 lb. and that the point of application is 5.46 ft. from A.

73. Couple Defined.—Two equal and opposite parallel forces acting at separate points constitute a *couple*. Referring to Fig. 53, it will be seen that a couple causes rotation only and that there can be no resultant. In order to produce equilibrium, a second couple having an equal and opposite effect is necessary. The distance (d) between the forces is called the *couple arm*. The actual couple is $F_1 \times d$ or $F_2 \times d$.

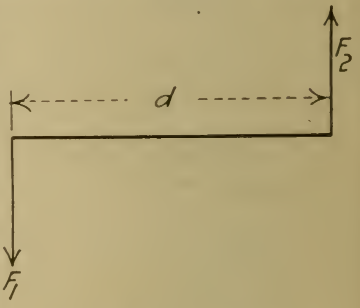


Fig. 53.—Couple.

Questions and Problems

1. State the conditions necessary for equilibrium of parallel forces.
2. Describe a laboratory experiment to verify the above conditions.
3. What is meant by the resultant of a system of parallel forces?
4. What is a couple? Couple arm? What kind of motion does a couple produce?
5. A painter's scaffold AB is 20 ft. long and weighs 100 lb. The painter, weighing 150 lb., is standing in the middle of the scaffold. Find the tension in each supporting rope.

6. Repeat problem 5, if he painter is standing 5 ft. from *A*.

7. Two men are carrying a load of 125 lb. on a uniform pole 20 ft. long. If the pole weighs 25 lb., where will the load have to be placed in order that one man shall carry twice as much as the other? Assume that the force exerted by each man acts 1 ft. from the end of the pole.

8. A light and a heavy horse are harnessed together. Where must the king pin in the evener be placed in order that the light horse shall pull only $\frac{3}{8}$ as much as the heavy horse?

9. It is customary to use at least three horses on a reaper. Design a whiffletree for three horses, so that each horse shall exert the same pull.

10. A uniform bridge 100 ft. long is supported by abutments *A* and *B*. The bridge weighs 175 tons and is carrying a locomotive weighing 60 tons. If the center of gravity of the locomotive is 30 ft. from *A*, find the vertical reaction of each abutment.

11. Repeat Problem 10, if the center of gravity of the locomotive is 40 ft. from *B*.

12. A uniform bar *AB* is 10 ft. long and weighs 20 lb. Three forces of 8 lb. each act directly down on the bar which is horizontal. Two of the forces act at the extremity of the bar and the other 4 ft. from *A*. Find the resultant and point of application of the forces.

13. Find the resultant and point of application, if the forces in Fig. 52 are doubled and the distances remain the same.

14. A door 7 ft. high and 3.5 ft. wide is supported by hinges 1 ft. from the upper and lower extremities. The door weighs 50 lb. Assuming each hinge to bear an equal load, what is the vertical and horizontal reaction at each hinge?

15. The lever of the safety valve shown in Fig. 54 is 29 in. long. The lever weighs 3 lb. and its center of gravity is 14 in. from the fulcrum *A*. The valve is 2 in. in diameter. The valve stem is attached to the lever 3.5 in. from *A*. Weight of the valve and stem is 2 lb. A ball weighing 25 lb. is suspended from *B*. Make a free body diagram from the above figures and compute the force in lb. per sq. in. necessary to "blow" the valve.

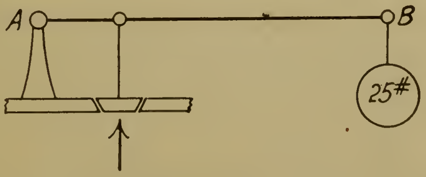


FIG. 54.

CHAPTER XI

EQUILIBRIUM OF NON-CONCURRENT FORCES

74. Non-concurrent Forces in Equilibrium.—Forces which do not pass through a common point and which are not all parallel, are called *non-concurrent forces.* Since non-concurrent forces may produce displacement as well as rotation, it is evident that such a system may not always be replaced by a single force or resultant.

Non-concurrent forces will be in equilibrium when:

1. *The resultant of the vertical forces is zero,*
2. *The resultant of the horizontal forces is zero,*
3. *The sum of the clockwise moments is equal to the sum of the counter-clockwise moments.*

If any of the three conditions stated above is not satisfied, there can be no equilibrium. The student should note that if the original forces are neither vertical nor horizontal, the forces should be resolved into their vertical and horizontal components. The components are then used as vertical and horizontal forces.

75. The Ladder.—The ladder problem offers an excellent opportunity for the application of the laws of non-concurrent forces. *AD* (Fig. 55) is a uniform ladder 10 ft. long and weighing 14 lb. The rungs are spaced 1 ft. apart. The weight (*W*) of the ladder is considered as a force of 14 lb. acting downward at the center of gravity. A load (*L*) of 40.25 lb. is suspended 3 ft. from *D*. The upper end of the ladder is just held free from the wall by a spring balance. Hence there is no friction between the ladder and the wall. The lower end of the ladder rests on a roller skate which in turn rests on platform scales. It is kept from slipping by means of a spring balance. The function of the roller skate is to eliminate friction between the ladder and the platform scales. The angle between the ladder and the wall is measured and found to be 44°. The spring balance readings are recorded also the reading of the platform scales (These values are used only for checking purposes). The balance readings are 17.5 lb. each and the platform scales reading minus the weight of the roller skate is 54.25 lb.

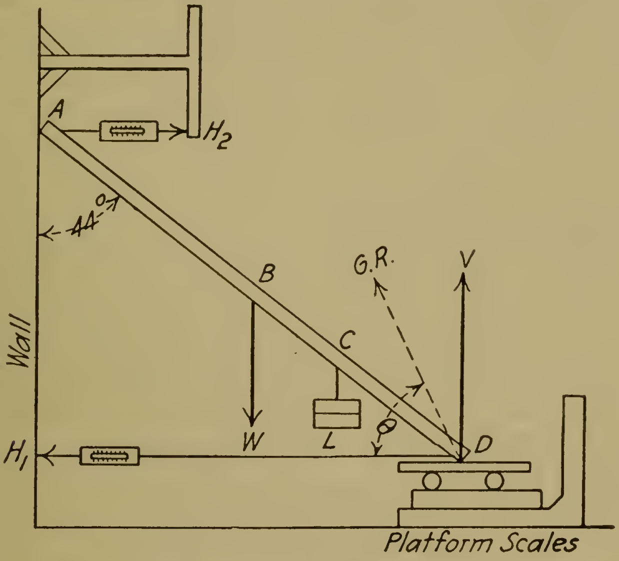


FIG. 55.—Ladder mounted for experimental purposes.

It is now desired to find H_1, H_2, V, the ground reaction ($G.R.$) and the angle (θ) of the ground reaction. It is evident that:

1. $H_1 = H_2$.
2. $V = L + W$,
3. $W \times BD \sin 44° + L \times CD \sin 44° = H_2 \times AD \cos 44°$.

As both H_1 and H_2 are unknown, it is necessary to take the moments about D as in (3).

$$40.25 \times 3 \times .695 + 14 \times 5 \times .695 = H_2 \times 10 \times .719$$
$$H_2 = 17.52 \text{ lb.} = H_1$$

Since the observed readings H_1 and H_2 were 17.5 lb. each, it is clear that the computed and observed values check very closely.

$$V = 40.25 + 14 = 54.25 \text{ lb.}$$

The above value of V checks exactly with the observed value shown by the platform scales.

The ground reaction ($G.R.$) is the resultant of V and H_1. $\overline{G.R.}^2 = \overline{H_1}^2 + V^2$, $G.R. = \sqrt{\overline{H_1}^2 + V^2}$, $G.R. = \sqrt{306.25 + 2837.64} = 53.3$ lb.

Tan $(\theta) = V/H_1 = 54.25/17.52 = 3.097$. By referring to the trigonometric tables in the appendix, the angle in the tangent column corresponding to the decimal 3.097 is found to be 72°.

76. The Wall Crane.—Figure 56 represents a laboratory model of a simple wall crane. The member *AB* (considered weightless) is held at rest by the tension (*T*) in the tie *DB*, the wall reactions (*V* and *H*) and the load (*L*). The compression in *AB* is designated by the letter *C*. Since *AB* is in equilibrium the following conditions prevail:

1. $H = C$,
2. $H = T \cos \theta$,
3. $V + T \sin \theta = L$,
4. $T \times 7 \sin \theta = L \times 4$.

Assuming *L* and θ to be given, *T* is found from equation (4). Substituting the value of *T* in equation (2), we get the values of *H* and *C*. Continuing the substitution in equation (3), the value of the vertical hinge reaction (*V*) is found.

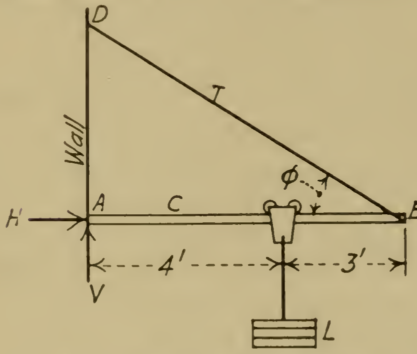


FIG. 56.—Wall crane.

Questions and Problems

1. What is meant by non-current forces?

2. Under what conditions will non-concurrent forces be in equilibrium?

3. A horizontal bar *AB* 4 ft. long and weighing 10 lb., is hinged to the wall at *A*. *B* is supported by a tie attached to the wall at *D*, making an angle of 40° with the vertical. If 100 lb. is suspended 1 ft. from *B*, find (*a*) the tension in the tie *DB*; (*b*) the compression in *AB*; (*c*) the vertical and horizontal reactions at *A* and *D*.

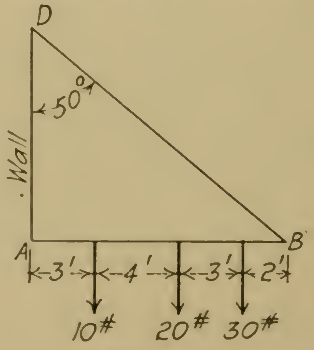


FIG. 57.

4. In Fig. 57, find the tension in *DB*; the compression in *AB*; and the vertical and horizontal reactions at *A* and *D*.

5. A uniform door 8 ft. high and 3.5 ft. wide, weighing 50 lb., is supported by two hinges 1 ft. from the top and bottom respectively. Assuming the total weight of the door to be borne by the lower hinge, find the vertical reaction at the lower hinge and the horizontal pull exerted by the upper hinge.

6. A ladder 20 ft. long makes an angle of 40° with a smooth wall. If the ladder weighs 35 lb. and its center of gravity is 9 ft. from the foot of the ladder, find (*a*) the horizontal reaction of the wall; (*b*) the vertical reaction at the foot of the ladder; (*c*) the friction between the ladder and the ground; (*d*) the ground reaction; (*e*) the angle of the ground reaction.

7. Repeat Problem 6, assuming a friction of 6 lb. at the top of the ladder.

8. Repeat Problem 7, if a painter weighing 175 lb. is standing 12 ft. up the ladder.

CHAPTER XII

COMMERCIAL AND LABORATORY STRUCTURES

77. Trusses.—A *truss* is a system of members (beams, bars, rods, etc.), joined together by pins or rivets, to form a rigid framework. While trusses may be of various shapes, modern engineering favors those of the *triangular* type,—consisting either of a single triangle or a collection of triangles. Triangular trusses are preferred on account of the fact that a triangle is the only geometrical figure which can not change its shape without changing the length of its sides. Trusses are so designed that the members are subject principally to *tension* or *compression*. As a rule, extraneous loads act as the joints. The material is so proportioned that deformations are practically negligible. Steady loads, as the weight of the material, etc., are called *dead* loads; varying loads, due to wind, snow, etc., are called *live* loads.

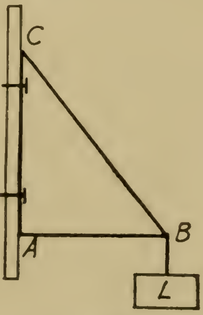


Fig. 58.—Simple truss.

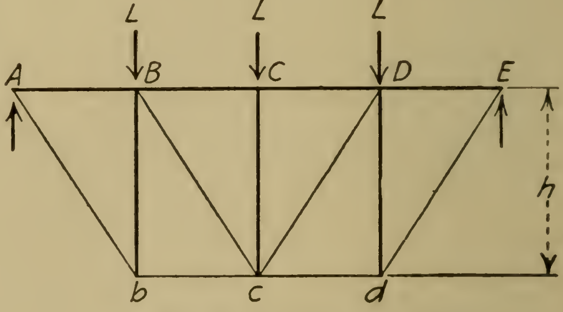


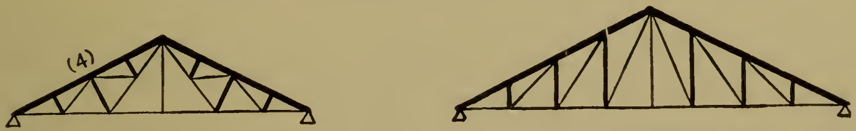
Fig. 59.—Compound truss.

Figure 58 represents a *simple* truss. The applied load (L) produces tension in CB and compression in AB.

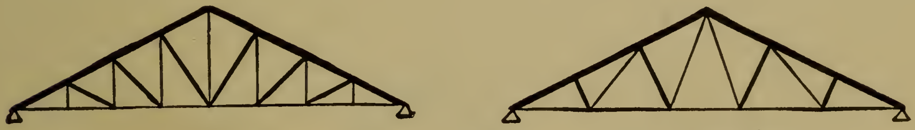
Figure 59 represents a *compound* deck truss supported at A and E, with loads (L) applied as shown. Tension members are shown with light lines; compression members with heavy lines. AE and bd are known as the upper and lower *chords* respectively. AB, BC, CD, DE, bc and cd are called *panels.* A, B, C, D, E, b, c and d are *joints* or *apexes.* The vertical distance h is the *height* or *depth* of the truss. The members between the chords, Ab, Bb, Bc, Cc, Dc, Dd and Ed, are *web members* or *braces* and are distinguished as *verticals* and *diagonals.* Web members in compression are usually called *struts*; tension members are usually called *ties* or *stays.*

78. Roof Trusses.—*Roof trusses* are rigid structures of metal or wood or a combination of the two, designed to support roofs. A few of the standard types will be touched upon below.

The Fink truss is commonly used for spans which do not exceed 100 ft. Figure 60(a) shows a 40 ft. span. The Fink truss is very economical due to the relative shortness of its struts. The Pratt truss (Fig. 60(b)) is very popular and is often used instead of the Fink truss. The Howe truss (Fig. 60(c)) is frequently used, especially if wood is to enter into the construction. The rafters and diagonals are generally of wood, the verticals of steel and the lower chords either of wood or steel. The triangular truss (Fig. 60(d)) is often used for short spans.



(a) Fink. (b) Pratt.



(c) Howe. (d) Triangular.

Fig. 60.—Types of roof trusses.

79. Bridge Trusses.—*Bridge trusses* are divided into two classes: *railroad bridges* and *highway bridges.* A few of the more common types will be discussed below.

Figure 61(a) represents a riveted Pratt railroad truss used for spans up to 160 ft. The Warren riveted truss (Fig. 61(*b*)) is used for spans from 120 to 160 ft. It is cheaper than the Pratt truss and just as satisfactory.

The quadrangular Warren truss (Fig. 62(*a*)) is commonly used for spans from 80 to 170 ft. The Baltimore truss (Fig. 162(*b*)) is used for long span bridges.

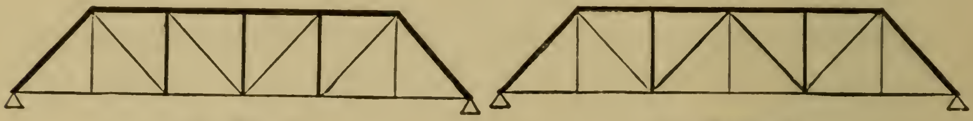

(*a*) Pratt. (*b*) Warren.

Fig. 61.—Types of railroad bridges.

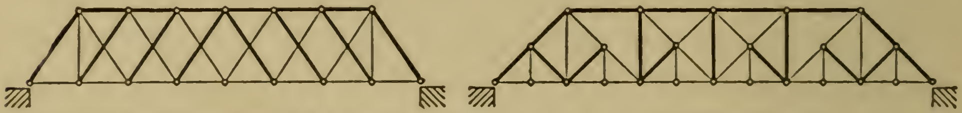

(*a*) Quadrangular Warren. (*b*) Baltimore.

Fig. 62.—Types of highway bridges.

80. Laboratory Study of a Roof Truss.—*ABC* is a laboratory model of a simple roof truss (Fig. 63). The members *AB* and *CB* weigh 2.5 lb. each and are hinged at *B*. The suspended weight *W* produces compression in *AB* and *CB*. The compression is balanced by the vertical and horizontal reactions at *A* and *C*. Inspection of the apparatus shows that

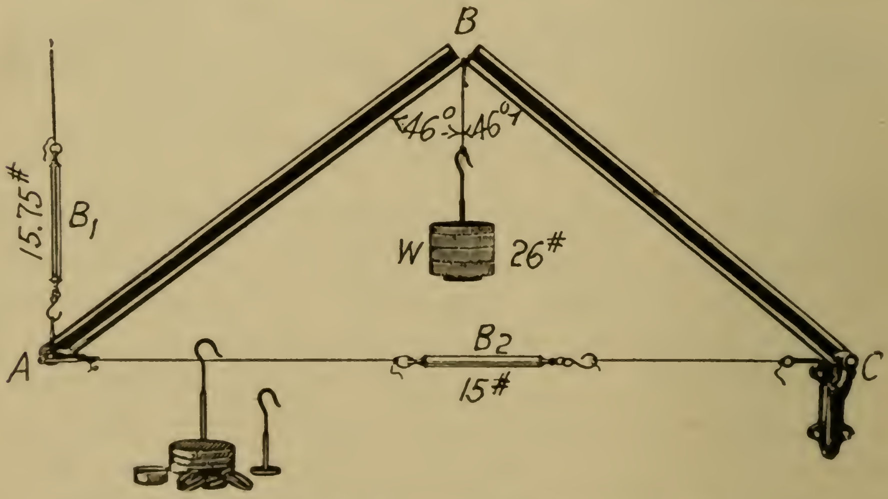


Fig. 63.—Roof truss mounted for laboratory use.

the compression in AB is the same as the compression in CB and that the reactions at A are the same as the reactions at C. It is assumed that one half of the weight of each member acts vertically downward at its extremities. Thus the total force acting downward at B is $W + 2.5$ lb. Balance 1 gives the total downward force at A and balance 2 the horizontal reaction at A. The balances are used only as checks.

The following experiment was done in the mechanics laboratory of the Wm. L. Dickinson High School. A weight of 26 lb. was suspended from B, making the total downward force $26 + 2.5$ or 28.5 lb. The apparatus was adjusted until B_1 was vertical and B_2 horizontal. B_1 read 15.75 lb. and B_2 read 15 lb. Angles ABW and CBW were measured and found to be 46° each.

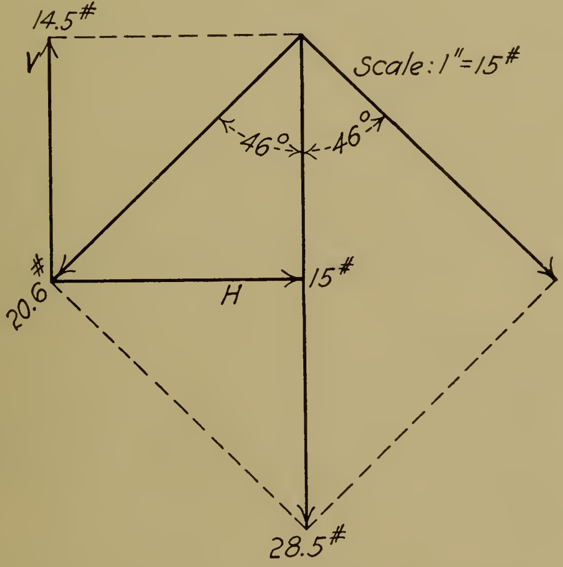


FIG. 64.—Force diagram for Fig. 63.

In order to find the compression in AB and BC and the vertical and horizontal reactions at A and C, a force diagram was constructed as shown in Fig. 64. Using a scale of 1 in. = 15 lb., a vector or force line was drawn to represent the total downward force of 28.5 lb. This force was resolved by the parallelogram method into two components at angles of

46° with the force. Each component was found to be 20.6 lb. Thus the compression in AB and BC is 20.6 lb.

It is evident that the compression in the member AB is just equal and opposite in direction to the resultant of the vertical and horizontal reactions V and H at A. Accordingly, the compressive force (20.6 lb.) was resolved into its vertical and horizontal components by the parallelogram method. It should be noted that the same scale is used throughout.

V was found to be 14.5 lb. Since one half of the weight of the member AB acts at A, it is necessary to add 1.25 lb. to V before checking with B_1. Then the computed value of V checks exactly with the actual value as shown by the spring balance. H was found to be 15 lb., checking exactly with B_2. As previously stated, the reactions at C are the same as at A and the compression in BC is the same as in AB. The results of the experiment were tabulated as follows.

Weight of member AB	2.50 lb.
Weight of member BC	2.50 lb.
Weight suspended (W)	26.00 lb
Total downward force at B	28.50 lb.
Reading of balance 1	15.75 lb.
Reading of balance 2	15.00 lb.
Angle ABW	46°.
Angle CBW	46°.
Calculated vertical component of AB	14.50 lb.
½ weight of AB (acting on A)	1.25 lb.
Total calculated downward force at A	15.75 lb.
(check) Vertical force recorded by balance 1	15.75 lb.
Difference	0
Calculated horizontal component of AB	15.00 lb.
(check) Horizontal force recorded by balance 2	15.00 lb.
Difference	0

81. Laboratory Study of a Simple Truss.—Figures 65 and 67 represent a laboratory model of a simple truss or, as it is often called, a "stick and tie." BC is a light compression member whose weight may be disregarded, fitting into a slot at B. The tie AC is a tension member. Balance 1 reads the tension (T) in AC and balance 2 reads the compression in

BC. These values are used as a check. Balance 1 is read directly. Balance 2 is pulled until *BC* just begins to leave the slot at *B*. The balance reading at this exact instant measures the compression in *BC*.

The following figures were obtained by two students in the Wm. L. Dickinson High School.

CASE I. *BC* HORIZONTAL

A weight of 10.75 lb. was suspended from *C* and the apparatus adjusted until *BC* was level. The angle *ACB* was measured and found to be 35°. The balance readings were taken and recorded. Balance 1 was 18.5 lb. and balance 2 was 15.25 lb. Using *C* as a free body, *T* and *R* were computed by trigonometry. Referring to Fig. 66, it is clear, since point *C* is in equilibrium, that:

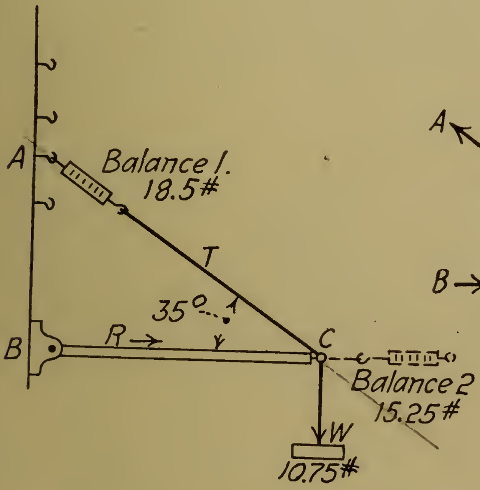


FIG. 65.—Simple truss mounted for laboratory use.

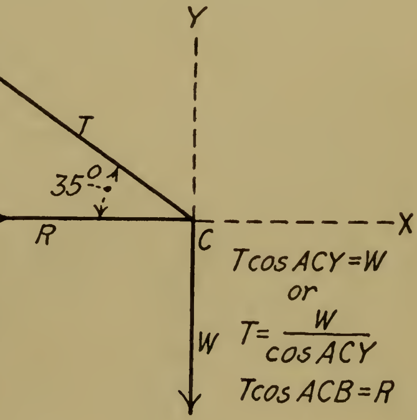


FIG. 66.—Force diagram for Fig. 65.

1. $T \cos ACY = W$ or $T = W/\cos ACY$,
2. $R = T \cos ACB$.

First T was found in equation (1) and then its value was substituted in equation (2) to find R.

1. $T = W/\cos 55°$, $T = 10.75/.574 = 18.70$ lb.,
2. $R = T\cos 35°$, $R = 18.70 \times .819, = 15.31$ lb.

TABULATION

Angle *ACB*	35°.
Angle *ACY*	55°.
Weight suspended (*W*)	10.75 lb.
T (calculated value)	18.70 lb.
T (observed value, balance 1)	18.50 lb.
Difference	.20 lb.
R (calculated value)	15.31 lb.
R (observed value, balance 2)	15.25 lb.
Difference	.06 lb.

CASE II. *BC* NOT HORIZONTAL

In this case, a suspended weight of 10 lb. was used and the apparatus adjusted until *BC* was at an angle as shown in Fig. 67. The angles *BCW* and *ACB* were measured and found to be 60° and 59° respectively. The balance readings were recorded as a check. Balance 1 read 10.3 lb.; balance 2 read 10.25 lb.

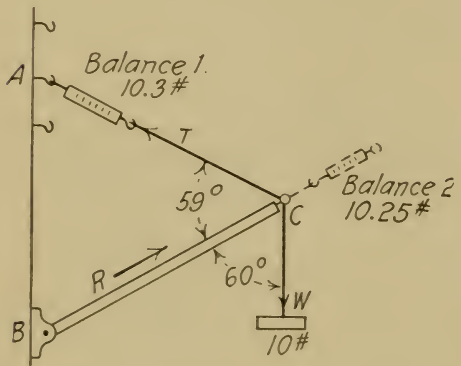


FIG. 67.—Simple truss mounted for laboratory use.

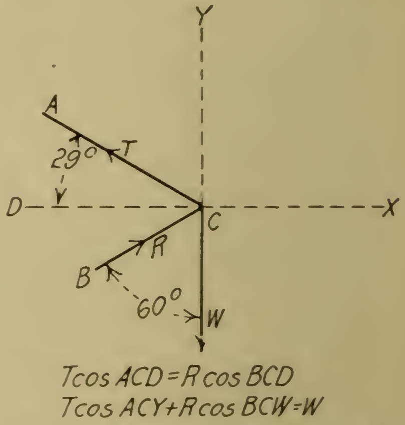


FIG. 68.—Force diagram for Fig. 67.

Using *C* as a free body, *T* and *R* were computed by trigonometry. Referring to the force diagram (Fig. 68), we see, since point *C* is in equilibrium, that:

1. $T \cos ACD = R \cos BCD$,
2. $T \cos ACY + R \cos BCW = W$.

Since *T* and *R* are both unknown, it is necessary to solve for them by the method of *simultaneous equations.* Putting in all known values, we have:

1. $T \cos 29° = R \cos 30°$, $T \times .875 = R \times .866$,
2. $T \cos 61° + R \cos 60° = W$, $T \times .485 + R \times .500 = 10$.

Simplifying and removing decimals:

1. $875\ T = 866\ R$,
2. $485\ T + 500\ R = 10{,}000$.

Since $T = 866\ R/875$, then, in equation (2):

$$485 \times 866\ R/875 + 500\ R = 10{,}000,$$
$$R = 10.32 \text{ lb.}$$

Substituting the value of R in equation (1):

$$875\ T = 866 \times 10.32,$$
$$T = 10.25 \text{ lb.}$$

Tabulation

Angle *BCW*	60°
Angle *ACB*	59°
Angle *BCD*	30°
Angle *ACD*	29°
Weight suspended (*W*)	10 lb.
T (calculated value)	10.25 lb.
T (observed value, balance 1)	10.30 lb.
Difference	.05 lb.
R (calculated value)	10.32 lb.
R (observed value, balance 2)	10.25 lb.
Difference	.07 lb.

82. Laboratory Study of a Simple Hoisting Crane.—Figure 69 represents a laboratory model of a simple hoisting crane. The angles and suspended weight (W) may be varied as desired. Given W, the weight of the boom AB and the necessary angles, the tensions (T_1 and T_2) may be computed, as well as the compression (R) in the boom. The problem is similar to that of the simple truss just studied. Since AB is fairly heavy, its weight may not be neglected. One half the weight of AB must be added to W for the total downward force (L).

Referring to Fig. 70 (force diagram for Fig. 69), it is evident that T_2 has the same tension as W (not L). Hence $T_2 = W$.

It is also evident that:

(a) $T_1 \cos 35° + T_2 \cos 53° = R \cos 65°$, and

(b) $T_1 \cos 55° + R \cos 25° = T_2 \cos 37° + L$.

Since $T_2 = W$, then T_1 and R are the only unknowns. T_1 and R are found by means of simultaneous equations as illustrated in the simple truss, previously studied. T_1 is checked by the balance C and R is checked by pulling out on AB with a spring balance.

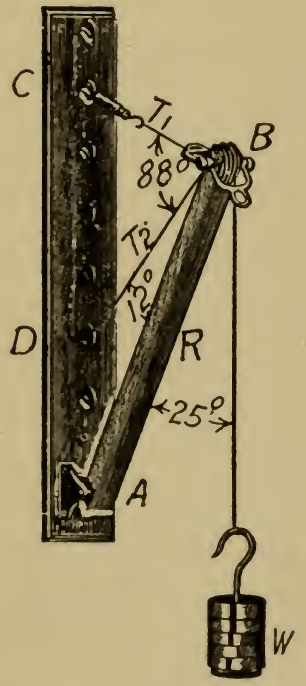


Fig. 69.—Laboratory type of hoisting crane.

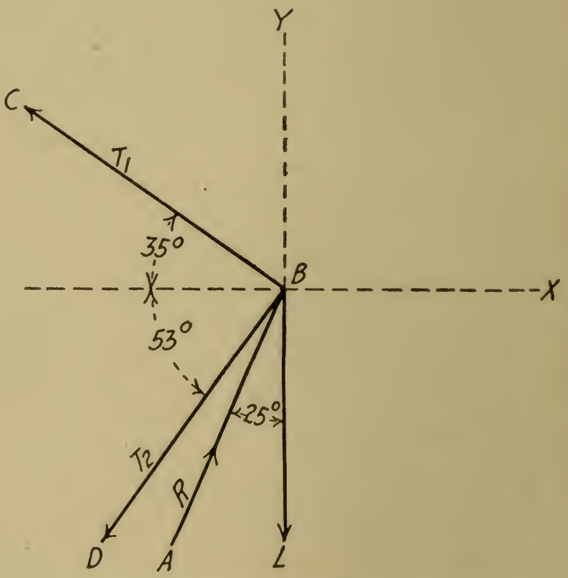


Fig. 70.—Force diagram for Fig. 69.

83. Laboratory Study of Shear Legs.—Figure 71 represents a laboratory model of a pair of shear legs such as is found around docks, etc. It will be seen that equilibrium is produced by the tension in *OD* and *OS* and by the compression in the legs *OA* and *OC*. It is desired to find *OD*, *OS*, *OA*, *OC* and the vertical and horizontal foot reactions at *A* and *C*. The apparatus is set up as shown and the tension in *OD* is checked by the balance B_1. The compression in *OA* is checked by pulling on B_2 along the line *OA* until *A* just begins to move from its support. The compression in *OC* is checked similarly. One half the weight of each leg must be added to W for the total load (L) at O.

Since the forces are not all in the same plane, assume OA and OC to be replaced by a single force OR in the plane DOW. It is evident that the imaginary force OR is the resultant of OD and OS. Given the total downward force at O (L) and the angles a and b, OD and OR are found graphically by the parallelogram method or trigonometrically.

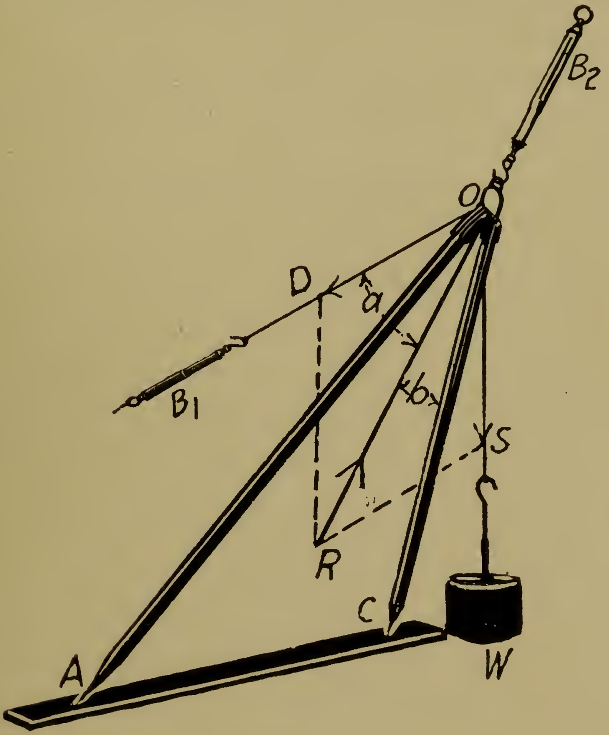


Fig. 71.—Laboratory type of shear legs.

Inspection of Fig. 71 shows that OR (just computed) is the resultant of OA and OC. Since these forces are in the same plane, OR is resolved either graphically or trigonometrically into its components OA and OC. Thus the compression in the legs is determined.

Questions and Problems

1. What is meant by a truss?

2. Why is a triangular truss favored by engineers?

3. Draw a compound deck truss and label each part.

4. What is a roof truss? Make a drawing to show four common types.

5. What is a bridge truss? Into two what classes may they be divided? Show, by drawings, two common types of each.

6. Describe a laboratory experiment to determine the static forces in (*a*) a simple roof truss; (*b*) a "stick and tie;" (*c*) a hoisting crane; (*d*) a pair of shear legs.

7. Find the compression in BA and BC and the vertical and horizontal reactions at A and C in Fig. 63, if the angles remain the same and W equals 20 lb.

8. Solve for T and R in Fig. 65, if the angles remain the same and W equals 12 lb.

CHAPTER XIII

ELASTICITY

84. Elasticity Explained.—Whenever a body is acted upon by an external force, a change in the shape of the body is produced. The applied force may act in three ways: (1) it may *stretch* the body; (2) it may *compress* the body; (3) it may *shear* the body. If the body has not been loaded too heavily, it will return to its original shape as soon as the displacing load has been removed. This is a manifestation of elasticity, a property which all matter possesses. Steel, glass, wood, rubber, etc. are elastic.

The *amount* of elasticity is measured, not by the ease with which the distortion is effected, but by the *difficulty* with which the distortion is effected. Steel is exceedingly elastic, while rubber is only moderately so. A unit force, applied to a unit length of steel, will produce much less distortion than the same force, applied to a piece of rubber of like length and cross-section. Steel, therefore, is more elastic than rubber.

85. Elasticity Defined.—Elasticity *is a general property of matter in consequence of which all bodies having undergone a change in shape, tend to resume their original shape as soon as the displacing force has been removed.*

86. Hooke's Law.—*If the applied forces are not too large, elastic deformations of all kinds are directly proportional to the forces producing them.* This law was first enunciated and demonstrated by Robert Hooke,[1] an Englishman, and bears his name.

Let us analyze the above law in order to understand clearly what is meant. Suppose that we have a piece of copper wire suspended from a rigid support and that the free end bears a scale pan of sufficient weight to take all the kinks out of the wire. Suppose, further, that a pointer moving over a graduated scale is attached a slight distance above the scale pan. If a weight of 5 lb. is placed in the scale pan and the pointer moves down 2 graduations, then a weight of 10 lb. will cause it to move down 4 graduations, and a weight of 15 lb. will cause it to move down 6 graduations. In short, if we double the pull, we double the stretch; if we triple the pull, we triple the stretch. In each case, the pointer will return to its first position as soon as the weight is removed.

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[1] Robert Hooke (1635–1703). English physicist. Made many inventions in physical and astronomical instruments.

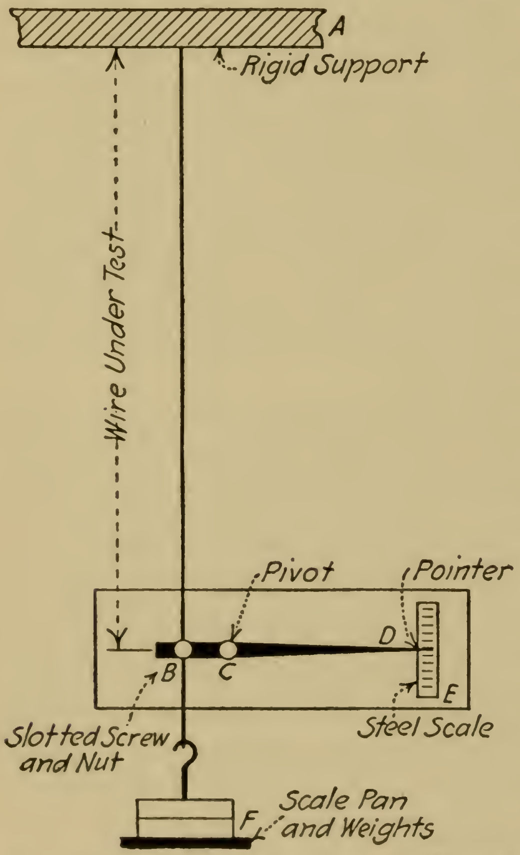

Fig. 72.—Apparatus to verify Hooke's law for tension.

The apparatus shown in Fig. 72 is very convenient for studying Hooke's law. A piece of german silver wire 104.5 in. long and .0005 sq. in. in cross-section is firmly clamped at the top to a rigid wall support (*A*). The opposite end of the wire carries a scale pan in which the various loads (*F*) are placed. The pointer (*D*) is attached to the wire at *B* and is pivoted at *C*. It will be seen that as *B* moves down, *D* will move up. In order to magnify the elongations of the wire and make more accurate reading possible, *DC* is made 10 times as long as *BC*. Hence, the movement of the pointer along the scale is always 10 times as much as the actual elongation of the wire.

The following experiment was performed by a student in the Wm. L. Dickinson High School with the apparatus and material just described. First a straightening load of 10 lb. was placed on the scale pan to take the kinks out of the wire. This weight is not counted in the calculations and is called the "zero" load. The pointer (*D*) was adjusted so that it was somewhat below the center of the scale (*E*) and the scale was moved until the pointer just coincided with an even scale division. A weight of 5 lb. was added to the scale pan and left 2 min. On being removed, it was found that the pointer returned exactly to its original position, showing the apparatus to be properly adjusted. If the pointer had not returned to its original position, there was either a loose connection or a sagging of the wall support.

Again the pointer reading at "zero" load was taken and recorded. A load of 2 lb. was now placed in the scale pan and, after 2 min., the pointer reading was carefully taken. The loads were increased, 2 lb. at a time, until 8 lb. had been added, the pointer reading being recorded in each case. The results were tabulated as follows:

Loads in lb.	Pointer readings in in.	Apparent elongations in in.	Actual elongations in in.
0	2.75		
2	3.00	0.25	0.025
4	3.25	0.50	0.050
6	3.50	0.75	0.075
8	3.75	1.00	0.100

A graph was made from the above data and is shown on page 80. Note that the load-elongation line is straight, denoting a *direct proportion.*

87. The Elastic Limit.—If the german silver wire, used in the experiment just described, had been subjected to further load, a point would have been reached at which the loads and deflections would have not been in direct proportion. The stretches would then increase in greater proportion than the loads, and the load-elongation line would bend to the right.

The pointer would not return to its original position when the loads were removed, and eventually the wire would break.

The stress beyond which an elastic material will not return to its original position when the load is removed, is called the elastic limit for that material. The elastic limit is difficult to determine exactly, but may be determined very closely.

88. The Yield Point.—After a material passes its elastic limit, a stress is reached at which the elongations continue without the addition of further load. This is called the *yield point* and shows that rupture is about to take place.

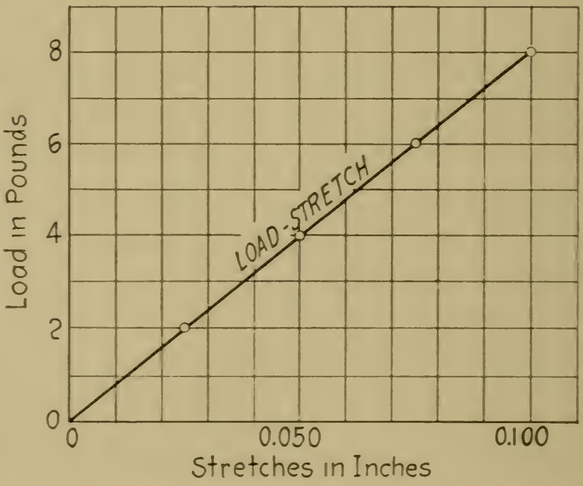

FIG. 73.—Graph showing relation of load and stretch for german silver wire.

89. Stress.—Whenever an elastic body is acted upon by a force, it is said to be under *stress.* The stress may be the result of a tensile load, in which the molecules tend to separate; it may be the result of a compressive load, in which the molecules tend to crowd together; or it may be the result of a shearing load, in which certain particles are caused to slide past others. In every case, the body resists the effort to change its molecular arrangement.

The internal resistance of a body to a change of shape is called stress. It is determined in amount by dividing the external force acting in lb. by the area in sq. in. over which the force acts. The area must always be taken at right angles to the force. Let us take a practical illustration.

Suppose a steel wire .10 sq. in. in cross-section is bearing a suspended load of 50 lb. The load of 50 lb. is evenly distributed over the area of the wire. If we wish to use a wire of 1 sq. in. cross-section and keep the same rate of tension, we must use a load of 500 lb. In either case, the wire is under a stress of 500 lb. per sq. in. The *stress* is simply *the load applied in lb. per sq. in.*[1]

$$\textit{Stress} = \frac{\textit{external force acting in lb.}}{\textit{area in sq. in. over which the force acts}}$$

90. Strain.—Whenever a body is subjected to a stress, a change of shape results. *The amount of change of size per unit of original size* is called *strain.* To illustrate: suppose we have a piece of copper wire about .04 in. in diameter and 72 in. long. Under a load of 5 lb., the wire will elongate .019 in. If a load of 10 lb. is used, the wire will elongate .038 in. In the first case, the *strain* will be .019/72 or .000263 inch per inch.[1] In the second case, it will be .038/72 or .000526 inch per inch.[2]

$$\textit{Strain} = \frac{\textit{change of size in inches}}{\textit{original size in inches}}$$

91. Young's Modulus.—*The mathematical relation of the stress and the strain* is called Young's modulus.

$$\textit{Young's modulus} = \frac{\textit{stress}}{\textit{strain}}$$

Young's modulus is also called the *coefficient* or *modulus of elasticity.* It is practically the same for tension as compression. The modulus for shearing strains will be considered later. The modulus for compression and tension, in the case of steel, will average about 30,000,000 lb. per sq. in.; for copper about 15,000,000 lb. per sq. in. These figures will vary somewhat, but may be taken as very close approximations.

We have seen, from the experiment with the german silver wire, that elastic deformations are directly proportional to the forces producing them, provided the elastic limit is not exceeded. This was stated as Hooke's law. We may now state Hooke's law thus: *Within the elastic limit, the strain is directly proportional to the stress.* Figure 74 shows this relation graphically. The data was taken from the experiment with the german silver wire and the stress and strain for each load was computed. The following graph should be carefully studied and thoroughly understood by the pupil.

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[1] May also be expressed in Kg./cm^2.

[2] May also be expressed in cm./cm.

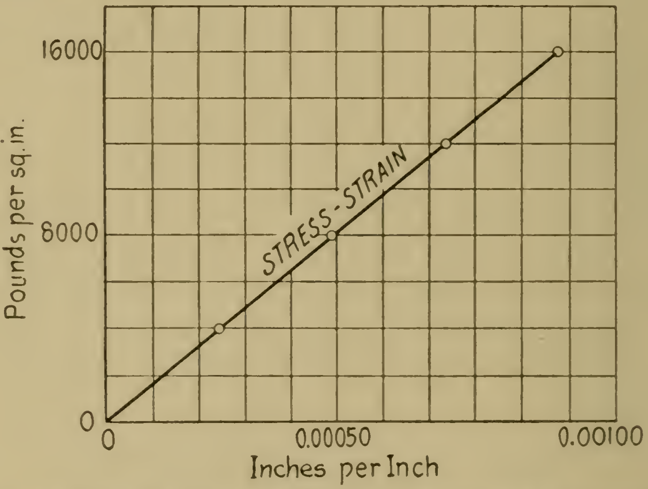

FIG. 74.—Graph showing relation of stress and strain for german silver wire.

92. Ultimate Strength.—The ultimate strength of an elastic material is the *load in lb. per sq. in. necessary to break or rupture the material.*[1] The rupture may be due to a tensile stress, a compressive stress or a shearing stress. Suppose a steel bar .5 sq. in. in cross-section ruptures under a load of 50,000 lb. The ultimate strength is 50,000/.5 or 100,000 lb. per sq. in. The ultimate strength for a body under tension is often called *tensile strength.* The tensile strength of mild steel will average about 70,000 lb. per sq. in. It will vary somewhat due to composition, temperature, etc.

93. Factor of Safety.—*The ratio of the breaking load to the working load for any material,* is called the factor of safety for that material. The factor of safety will necessarily depend on the nature of the load. Under a steady load, steel should have a factor of 4; under a varying load a factor of 6; under a load in which the stresses are liable to occur sharply, a factor of 10. In machines subject to sudden overloads, the factor of safety is made very high to avoid any chance of fatal accidents. It is evident that all members which have to bear frequent and sudden overloads should have a high percentage of overstrength.

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[1] May also be expressed in Kg./cm.^{2}.

94. Elastic Fatigue.—Practical experience and experiment teaches us that an elastic material is more liable to break under a *repeated* load than a *steady* load of the same size. This is especially true when the stresses consist both of tensions and compressions. The tendency to rupture under repeated strain is due to what is known as *elastic fatigue* and results in the destruction of the cohesive force at the point of rupture. The rear axle of an automobile occasionally breaks. This is generally due to repeated twisting strains. A piece of copper wire twisted back and forth will soon undergo elastic fatigue and break at the point of strain.

95. Shear Explained.—When a body is subjected to a *shearing* stress, certain particles, of which the body is composed, tend to slide by other particles. This is well illustrated in the case of a pair of metal shears, the metal being *sheared* apart where the blades come together. Planing, turning and punching are shearing actions.

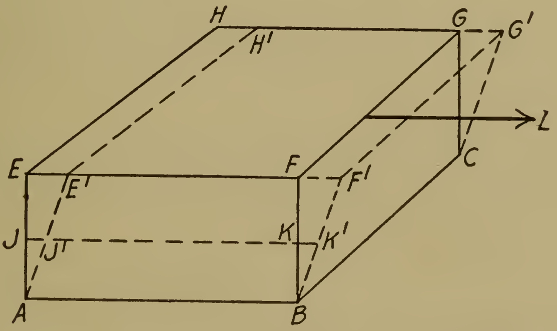

FIG. 75.—Diagram to illustrate simple shear.

In order to understand the nature of a simple shear, let us refer to Fig. 75. Here we have a rectangular, elastic body ABC 4 × 4 in. on the top face and 2 in. high. Assume the face ABC to be attached rigidly to the surface on which it rests, so that there can be no movement at the bottom. A force of 80 lb. is attached to the face $EFGH$ and is evenly distributed over the 16 sq. in. This force (L) will move the horizontal layers to the right, the movement varying from maximum at the top to zero at the bottom. Each succeeding upper layer will have a greater displacement to the right. Actually, there is also a bending tendency present. It is sufficient for our purpose, however, to consider only the simple shear, leaving the rest to more advanced books.

96. Shearing Stress.—Shearing stress is equal to *the force acting in lb. divided by the area in sq. in. over which the force acts.* In Fig. 75, the shearing stress is 80/16 or 5 lb./in.^{2} It may also be expressed in Kg./cm.^{2}

97. Shearing Strain.—Shearing strain is equal to *the horizontal movement in inches of a particle of a body* 1 *inch above the plane to which it is attached.* Referring to Fig. 75, let $AJ = 1$ inch and $JJ' = .0006$ inch. The shearing strain is therefore .0006 inch per inch. Suppose that $EE' = .001$ inch and that $AE = 3$ inches. The shearing strain will then be .001/3 or .00033 inch per inch. Shearing strain may also be expressed in cm./cm.

98. Modulus of Rigidity.—The modulus of rigidity (also called the modulus of elasticity for shear) is *the ratio of the shearing stress and shearing strain.*

$$\textit{Modulus of rigidity} = \frac{\textit{shearing stress}}{\textit{shearing strain}}.$$

99. Practical Illustrations of Shear.—The rivets used in fastening together boiler plates, etc., are subject to shearing stresses. Figure 76 shows a single-riveted *lap joint.* The rivet is subject to a shearing stress at "*a*" and will fail at that point if the stress is of sufficient magnitude. This is an example of *single shear.*

Figures 77 and 78 represent single and double-riveted *butt joints.* The rivets are liable to failure both at "*b*" and “c” and are said to be in *double shear.* Figure 79 shows rivets having failed under single and double shear respectively.

Illustrative Problem.—What force is required to punch a ¾ in. hole in a steel plate ½ in. thick? Shearing strength of the material is 40,000 lb./in.^{2}

Solution.—Area under shear $= .75 \times 3.1416 \times .50 = 1.178$ sq. in. $1.178 \times 40{,}000 = 47{,}120$ lb. *Ans.*

Illustrative Problem.—The head of a 1 in. machine bolt is ¾ in. thick. Find (1) the force necessary to shear the bolt off at right angles to its length; (2) the shearing stress tending to strip the head from the bolt due to an applied force of 10,000 lb. Shearing strength of the material is 40,000 lb./in.^{2}

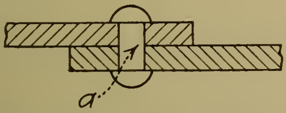

FIG. 76.—Single-riveted lap joint.

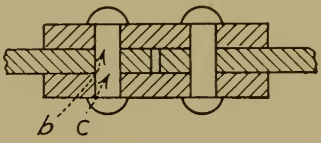

FIG. 77.—Single-riveted butt joint.

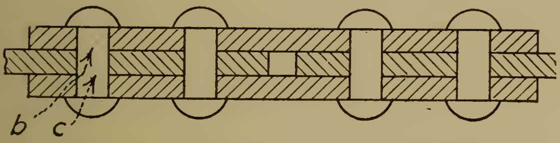

FIG. 78.—Double-riveted butt joint.

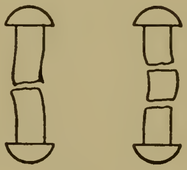

FIG. 79.—Failure of rivets due to single and double shear.

Solution.—(1) Area under shear $= 1 \times 1 \times .7854 = .7854$ sq. in. $.7854 \times 40{,}000 = 31{,}416$ lb. *Ans.*

2. Area under shear $= 1 \times 3.1416 \times .75 = 2.356$ sq. in. $10{,}000/2.356 = 4{,}244$ lb./in.^{2} *Ans.*

Questions and Problems

1. Define elasticity.

2. What effects may be produced upon an elastic body by an external force?

3. State and explain Hooke's law.

4. Define stress, strain, elastic limit, yield point.

5. What is meant by Young's modulus?

6. Describe an experiment to determine the relation between stress and strain for an elastic body.

7. Define ultimate strength, tensile strength, compressive strength, shearing strength, factor of safety, elastic fatigue.

8. Define shear and give examples of shearing actions.

9. Show, using diagram, how to determine stress and strain for simple shear.

10. What is meant by the modulus of rigidity?

11. A steel strut having a cross-section of 4 sq. in. is subjected to a compressive force of 2 tons. Compute the stress.

12. A uniform steel bar 2 sq. in. in cross-section ruptures under an applied tensile force of 200,000 lb. What is the ultimate strength?

13. If the above bar is of wrought iron, how large a force will be required for rupture? Tensile strength of wrought iron = 50,000 lb./in.^{2}

14. A wire 2 mm. in diameter breaks under a load of 100 Kg. If the diameter is increased to 4 mm., what load will be necessary for rupture?

15. A steel rod 6 ft. long and 1 sq. in. in cross-section is subjected to a tensile load of 10,000 lb. Find the elongation in inches. Modulus of elasticity = 30,000,000 lb./in.^{2}

16. A hard, drawn copper rod 10 ft. long and 1 sq. in. in cross-section stretches .100 in. Find the tensile load necessary to produce the elongation. Modulus of elasticity 17,600,000 lb./in.^{2}

17. A steel bar 1 sq. in. in cross-section and 6 ft. long stretches .024 in. under an applied load of 5 tons. Determine the modulus of elasticity for the material.

18. A horizontal beam 4 sq. in. in cross-section is securely fastened at one end. If a load of 10,000 lb. at right angles to the beam is applied 10 in. from the attached end, find the deflection of the beam at the point where the load is applied. Modulus of rigidity is 12,000,000 lb./in.^{2}

19. A steel plate $\frac{1}{2}$ in. thick has an ultimate shearing strength of 40,000 lb./in.^{2} What force is required to punch a $\frac{1}{4}$ in. hole through the plate?

20. Repeat problem 19 for a $\frac{3}{8}$ in. hole.

21. A wrought iron rivet $\frac{1}{4}$ in. in diameter is sheared off at right angles to its length. If the shearing strength of wrought iron is 40,000 lb./in.^{2}, what was the applied force?

22. The head of a 1 in. steel machine bolt is $\frac{7}{8}$ in. thick. A force of 12,000 lb. is applied in such a way that there is a tendency to strip the head from the bolt. Find the shearing stress due to the applied load.

23. In problem 22, if the force is increased gradually, will the bolt fail due to a tensile stress or a shearing stress? Explain.

CHAPTER XIV

WORK

100. Work Defined and Explained.—*Work is the result accomplished when a force acts through a distance.* The force may keep the motion of a body constant; increase, decrease or change the direction of the motion; or cause the body to undergo a change of shape or size. Common examples of work are a hoisting engine lifting concrete; a man climbing a mountain; a horse drawing a wagon; punching holes in sheet iron; stopping an automobile by means of the brakes, etc. Various other examples will occur to the student. The foundation of a building, although it exerts an enormous upward force, *does no work,* because the weight supported by the force is not moved. Force, then does not always result in work. This point should always be kept in mind.

101. How Work is Measured.—The work done upon any body is measured by the *product of the force acting* and *the distance through which the force acts.*

$$\text{Work done} = \text{Force} \times \text{Distance} = F \times S$$

102. Units of Work.—Various units may be used to express the amount of work done. If a 10 lb. weight is lifted vertically 10 ft., 100 ft.-lb. of work results. The same work may be expressed as 1,200 in.-lb. or .05 of a ft.-ton. Further, a weight of 1 Kg. lifted vertically through a height of 10 meters results in 10 kilogram-meters of work. 10 Kg.-m. may also be expressed as 10,000 g.-m. or 1,000,000 g.-cm. The more common units are given below.

UNITS OF WORK

(*a*) The *erg* is the work done when a force of 1 dyne[1] acts through a displacement of 1 centimeter. Since the erg is a very small unit, the *joule* is often used. A joule is equal to 10,000,000 ergs.

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[1] 1 dyne = .00102 g. 1 lb. = 445,000 dynes.

(*b*) The *kilogram-meter* is the work done when a force of 1 kilogram acts through a displacement of 1 meter.

(*c*) The *foot-pound* is the work done when a force of 1 pound acts through a displacement of 1 foot.

103. Time Not a Factor in Work.—The element of time is not considered in an expression of work. In a scientific sense, work refers only to the result accomplished, regardless of the time consumed in obtaining the result. For example, it will require 20,000 ft.-lb. of work to raise 1,000 lb. of pig iron through a vertical height of 20 ft. It is evident that the amount of work will be the same if the iron is lifted all in one operation or if each pig is lifted separately.

104. Further Discussion of Work.—If a body weighing 100 lb. is raised vertically 10 ft., 1,000 ft.-lb. of work is done. If the same body is pulled 10 ft. horizontally across a floor, less work is done as the force required to pull is less than the force required to lift. The pulling force will depend on the friction between the bodies in contact, and is always less than the lifting force.

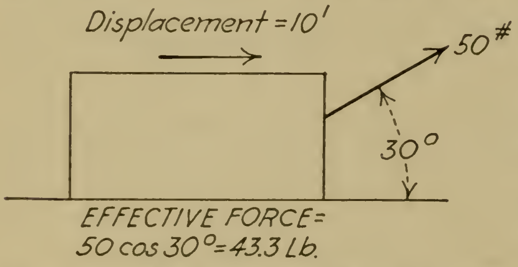

FIG. 80.—Work done equals 433 ft.-lb.

In case it is desired to compute the work done by a force acting at an oblique angle, it is necessary to find the component of the force in the direction in which the body moves. Suppose (Fig. 80) it is desired to find the work done by a force of 50 lb., acting at an angle of 30°. The body is moved horizontally 10 ft. The work done is *not*

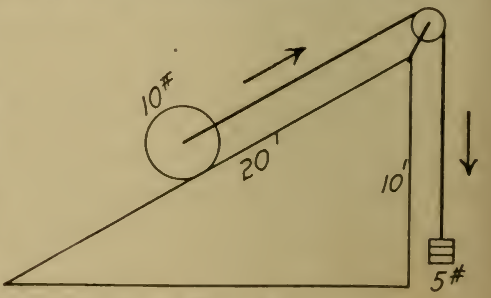

FIG. 81.

500 ft.-lb. It is 433 ft.-lb. and is computed as follows:

The horizontal component of 50 lb. = 50 × cos 30° = 50 × .866 = 43.3 lb. 43.3 × 10 = 433 ft.-lb.

The work done in moving a body uniformly up a frictionless inclined plane may be determined in two ways. Suppose, referring to Fig. 81, that a force of 5 lb. is necessary to move a body weighing 10 lb. up a plane 20 ft. long and 10 ft. high.

The work = *weight* × *height* = 10 × 10 = 100 ft.-lb. The work also = *force* × *length* = 5 × 20 = 100 ft.-lb.

105. Work Diagrams.—It is often convenient to represent

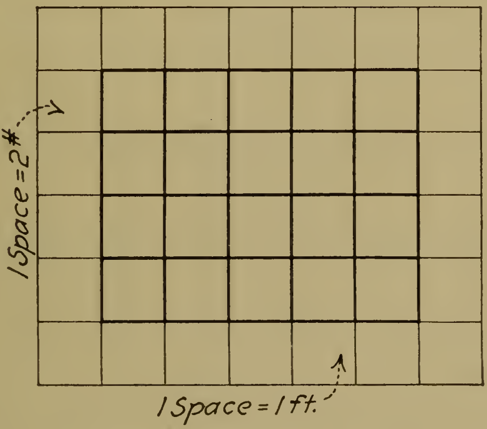

Fig. 82.—Diagram representing 40 ft.-lb. of work.

work done by a *work diagram*,—in which the amount of work is proportional to the area of the diagram. Suppose we wish to represent a constant force of 8 lb. acting through a distance of 5 ft. Adopting some convenient scale (such as 1 space = 2 lb. and 1 space = 1 ft.), we construct a diagram as shown in Fig. 82. It is evident that each square space = 2 ft.-lb. and that the total number of square spaces represent the entire work done or 40 ft.-lb. (20 × 2).

Figure 83 represents the *net work* done by the head end of a Corliss steam engine cylinder on 1 sq. in. of the piston during one revolution of the crank shaft. The diagram was taken by means of a device called a steam indicator. The line *abcdea* represents the steam pressure at any point in the outward and return stroke. It is evident that the effective pressure (P) at any chosen place will be proportional to a vertical line (ordinate) connecting the upper and lower extremities. By drawing a series of such ordinates at equal intervals and averaging them, the mean effective pressure for the entire working stroke can be determined, if the vertical scale is known. Since 1 in. = 70 lb., the mean effective pressure will be about 35 lb./sq. in. for the diagram shown here. The stroke is 2 ft.; hence the useful work on one sq. in. of the head end of the piston for one revolution will be 70 ft.-lb. (35 × 2). 70 ft.-lb. also represents the area (average height × length) of the diagram in terms of the scale used.

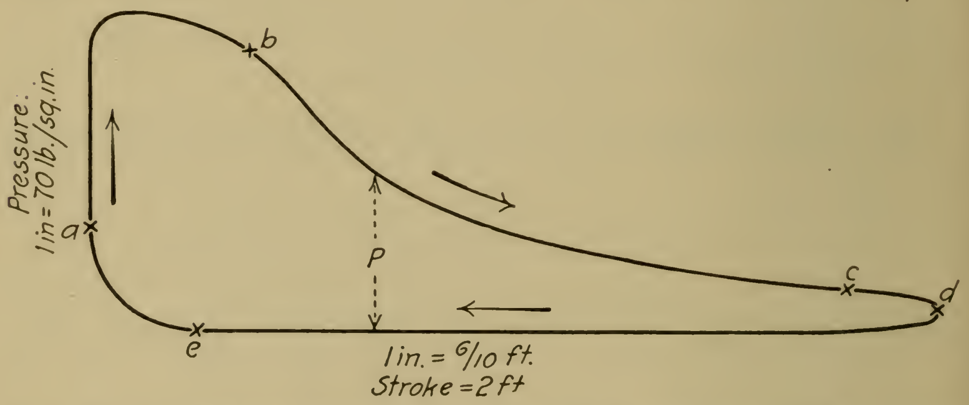

FIG. 83.—Diagram representing work done by the crank end of a Corliss steam engine cylinder during one revolution of the crank.

The student should note that: a = steam admitted into the cylinder; b = steam is cut off; c = exhaust opens; d = exhaust stroke begins; and e = exhaust closes and compression begins.

Questions and Problems

1. What is meant by work? Give various examples of work

2. What is the general formula for work done?

3. Name and define the units of work.

4. Discuss "time as an element in work."

5. State two ways of computing the work done on an inclined plane.

6. A force of 1 dyne acts through 10 cm. How much work is done?

7. An automobile weighing 2,000 Kg. travels 1 Km. up a 2 per cent. grade. Find the work done in Kg.-meters.

8. An elevator weighs 1,500 lb. more than its counter-weight. How much work is done if it rises 50 ft.?

9. A block of wood weighing 4,200 lb. is 8 ft. long, 4 ft. wide and 3 ft. thick. If the block is lying on the 8 ft. × 4 ft. side, how much work is necessary to turn the block on the 3 × 4 ft. side?

10. How many foot-pounds of work will be done by a gasoline engine of 15 per cent. efficiency on 10 gallons of gas? Assume 2,000 British thermal units per lb. of gas (1 B.t.u. = 780 foot-pounds).

11. A hoisting engine burns 1 ton of coal during the day. If the engine is 2 per cent. efficient, how much work will it do in a day? (1 lb. coal = 13,000 B.t.u.)

12. A force acts through 10 ft. against a varying resistance. The successive resistances in pounds at the beginning of each foot are as follows: 50, 55, 60, 58, 51, 52, 63, 60, 57, 49, 51. Construct a work diagram, drawn to scale, and determine the amount of work done.

CHAPTER XV

POWER

106. Power Defined.—We have seen that time is not an element in work. For example, it is possible, under certain conditions, for a light horse to do as much work as a heavy horse, provided the light horse is allowed more time to complete his task. The heavy horse is said to possess the greater *power,* however, as he can do the work in a shorter time. Power concerns itself both with the *work done* and the *time.* A locomotive will do many times as much work in a given time as a hoisting engine and therefore has the greater power. *Power is an expression of the rate at which work is done.*

$$\text{Power} = \frac{\text{work done}}{\text{time}}$$

107. Units of Power.—The units of power in general use are the *horsepower,* the *watt* and the *kilowatt.* The watt and kilowatt are coming into popularity very rapidly. Electric light bulbs are rated entirely in watts. Electric motors and marine engines are commonly rated in kilowatts. The horsepower is still widely used and is very important.

108. The Horsepower.—James Watt[1] estimated that a heavy work horse, traveling at an average rate of 2.5 miles per hour, could lift a weight of 150 lb. by means of a rope and pulley. This is equivalent to 33,000 ft.-lb. of work per minute or 550 ft.-lb. per second. Watt's estimate is probably inaccurate, yet it furnishes a very satisfactory basis for comparisons of power. *Whenever work is being done at the rate of* 33,000 *ft.-lb. per minute, one horsepower is being expended.*

$$\text{Horsepower} = \frac{\text{ft.-lb. of work per minute}}{33{,}000}$$

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[1] James Watt (1736–1819). Scottish engineer. Invented the first condensing steam engine and the first centrifugal governor. First used the steam indicator to determine the amount of work done by a steam engine.

109. The Watt and Kilowatt.—The power unit in the *c.g.s.* system is an *erg per second.* For practical purposes, it is customary to use a joule per second (10,000,000 ergs per second). The latter unit is called a *watt* in honor of James Watt. One horsepower is equivalent to 746 watts. Since there are 1,000 watts in a *kilowatt,* it is evident that one horsepower is nearly equivalent to ¾ of a kilowatt and, conversely, that one kilowatt is slightly more than ⅘ of a horsepower. Electrically, the watt is the work done in one second by a current of one ampere flowing under a pressure of one volt.

1 horsepower (hp.) = 746 watts
1 kilowatt (kw.) = 1,000 watts
1 horsepower = ¾ kw. (approx.)
1 kilowatt = 1⅓ hp. (approx.)

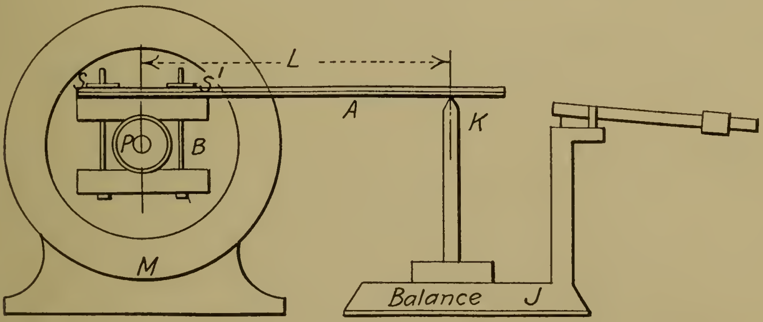

Fig. 84.—Prony brake mounted for power test of an electric motor.

110. Brake Horsepower (b.hp.).—The *brake method* is used in determining the power delivered by a rotating shaft or pulley. It is also known as the *absorption method,* since the power transmitted is absorbed and the mechanical energy of the rotating body is transformed into heat energy. A device called the *prony brake* is used to determine brake horsepower. It is described in the succeeding paragraphs.

The following experiment was performed by a student in the Dickinson High School and serves to illustrate the construction and operation of the prony brake. Referring to Fig. 84, *M* is an electric motor rated to give 2 hp. at 1,500 r.p.m. and 108 volts. In order to check up the rating, the motor is fitted with a hollow iron pulley (*P*), which is rotated against the friction of the adjustable brake (*B*). The brake is lined with some heat resisting material, such as is used for brake lining of an automobile. It carries an arm (*A*) which rests on a knife edge (*K*). The knife edge rests on the platform balance (*J*). The power is turned on and the thumb screws (*S* and *S′*) are tightened until the speed of the motor is approximately 1,500 r.p.m. in a clockwise direction. Meanwhile, a stream of water is directed against the pulley to keep it from overheating. From the following final readings, the horsepower was computed.

Force (*F*) exerted by arm on balance	7 lb.
Length (*L*) of arm	1 ft.
Revolutions per minute (r.p.m.)	1,530

$$B.hp. = \frac{F \times 2L \times 3.1416 \times r.p.m.}{33{,}000},$$

$$B.hp. = \frac{7 \times 2 \times 3.1416 \times 1{,}530}{33{,}000} = 2.04 \text{ hp.}$$

It will be noted that the numerator of the above fraction is the foot-pounds of work which it is assumed the force (*F*) would do each minute, in rotating through a distance of $2L \times 3.1416$ every revolution for 1,530 revolutions.

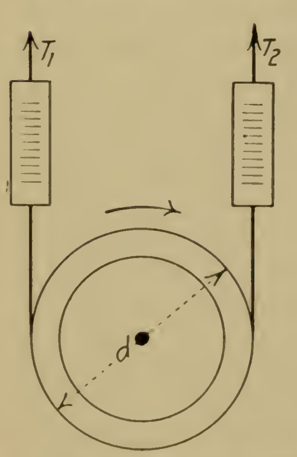

FIG. 85.—Belt form of prony brake.

Another form of the prony brake is shown in Fig. 85. *B* represents the balance wheel of an automobile from which the clutch has been removed. A belt of heat resisting material is carried around the wheel and secured at either end by two spring balances (T_1 and T_2). The throttle is opened and the balances tightened until the wheel is making 1,000 *r.p.m.* The balance readings are taken and the difference in tension noted. The wheel is kept from overheating as in the previous experiment. From the following data the horsepower is computed.

Diameter (d) of wheel	1.5 ft.
Difference in tension ($T_2 - T_1$)	200 lb.
Revolutions per min. (r.p.m.)	1,000
Width of belt	.25 in.

$$B.hp. = \frac{(T_2 - T_1) \times d \times 3.1416 \times \text{r.p.m.},}{33{,}000}$$

$$B.hp. = \frac{200 \times 1.52^1 \times 3.1416 \times 1{,}000}{33{,}000} = 29 \text{ hp.}$$

111. S. A. E. Determination of Horsepower.—The determination of horse power by the *S. A. E.* (Society of Automotive Engineers) formula is purely an arbitrary calculation and is used only in computing the horsepower of automobile motors. The *S. A. E.* method is derived from the brake method and has been useful for comparative purposes such as the amount paid for license fee, etc.

$$Hp. = \frac{D^2N}{2.5} \text{ in which, } \left\{\begin{array}{ll} D & = \text{bore of cylinders in inches,} \\ N & = \text{number of cylinders,} \\ 2.5 & = \text{a constant.} \end{array}\right.$$

The above formula assumes a piston speed of 1,000 ft. per min., a mean effective cylinder pressure of 90 lb. per sq. in., and a mechanical efficiency of 75 per cent. Since a gasoline motor delivers more power at a higher rate of speed and since the average automobile motor has a piston speed of 1,500 ft. per min., it is evident that the *S. A. E.* formula is more or less of a makeshift. To-day many motors are tested by the brake method before leaving the factory.

112. Indicated Horsepower (i.hp.).—The *indicated horsepower* method is confined almost exclusively to the steam engine, although it may be used for internal combustion engines. It determines the *power developed* in the cylinder and *not the power transmitted.* Indicated horsepower will always *exceed* brake horsepower, as it makes no deduction for frictional losses.

In finding *i.hp.*, it is necessary to make use of work diagrams as illustrated in Fig. 83. The diagrams are taken by a

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[1] The thickness of the belt is added to the diameter.

special device called an *indicator* and from the diagrams the mean effective pressure is found for the stroke. For the actual method of taking indicator diagrams, the student is referred to books dealing with steam and gas engines.

$$I.hp. = \frac{PLAN}{33,000} \text{ in which, } \begin{cases} P = \text{mean effective pressure in lb. per sq. in.,} \\ L = \text{length of stroke in ft.,} \\ A = \text{Area of piston head in sq. in.} \\ N = \text{Working strokes per min.} \end{cases}$$

In double acting engines the head and crank ends must be figured separately and added together for the *total* horsepower.

113. Mechanical Efficiency.—The *mechanical efficiency* of an engine is the ratio of its brake horsepower and indicated horsepower.

$$M.e. = \frac{\textit{brake horsepower}}{\textit{indicated horsepower}}$$

Questions and Problems

1. Define and give an example of power.

2. Give the general formula for power.

3. Define (*a*) horsepower; (*b*) watt; (*c*) kilowatt.

4. State the mathematical relation between the above units.

5. State three different methods of determining horsepower.

6. Describe in detail two different ways of determining b.hp.

7. What is the *S. A. E.* formula? Is it accurate? Why?

8. State and explain the formula for i.hp.

9. Why is b.hp. less than i.hp?

10. How may the mechanical efficiency of an engine be determined?

11. A man weighing 175 lb. climbs a ladder through a vertical distance of 30 ft. in 1 min. What hp. did he expend?

12. A Goulds triplex pump lifts 40 lb. of water a vertical distance of 5 ft. in 1 min. Compute power expended.

13. A hoisting engine (gears 80 per cent. efficient) is used in lifting cement to the top of a building 50 ft. high. If 1,000 tons is to be lifted through a working day of 8 hr., what is the average horsepower expended?

14. The difference in tension between two sides of a belt is 50 lb. If the belt is running at the rate of 2,500 ft. per minute, what horsepower is being transmitted? Express the answer also in watts and kilowatts

15. The Cole "Aero Eight" develops horsepower in excess of 80.

If the cylinders are 3½ in. bore, what is the horsepower according to the *S. A. E.* rating?

16. An automobile motor has an indicated hp. of 35 and a brake hp. of 30. What is the mechanical efficiency of the motor?

17. In computing the power of an electric motor by a prony brake, the following data was obtained: net force of brake arm on platform balance 11 lb.; length of brake arm 14 in.; r.p.m. 1100. Find horsepower and kilowatts transmitted by the motor.

18. A belt prony brake is used in figuring the hp. of a gasoline motor. From the following data compute the power transmitted by the motor: difference in tension of balances = 100 lb.; diameter of pulley = 2 ft.; r.p.m. = 1,500.

19. In determining the horsepower of the Corliss steam engine in the Dickinson High School power plant, a group of students reported the following data: mean effective pressure = 30 lb. per sq. in.; length of stroke = 24 in.; diameter of piston = 18 in.; diameter of piston rod = 4 in.; r.p.m. = 200. Compute the indicated horsepower of the engine. (The area of the piston rod must be subtracted from the area of the piston on the "crank end.")

CHAPTER XVI

ENERGY

114. Energy.—*Energy is the ability to do work.* A body possessing energy may or may not do work. For instance, a stick of dynamite possesses a large amount of energy, but the energy will remain latent unless the dynamite is exploded. A pound of coal contains over 10,000,000 ft.-lb. of energy. No work is done, however, unless the coal is burned and the heat energy transformed into mechanical energy, as in the steam power plant. *Energy* should never be confused with *force or power;* they are entirely different terms.

115. Fixed Energy.—Energy stored up in a body is called *fixed energy.* Food contains stored energy from which the body derives its energy and ability to do work. Gasoline contains stored energy, every pound furnishing about 15,000,000 ft.-lb. Fixed energy of this kind is determined by burning the substance and measuring the heat energy given off during the combustion.

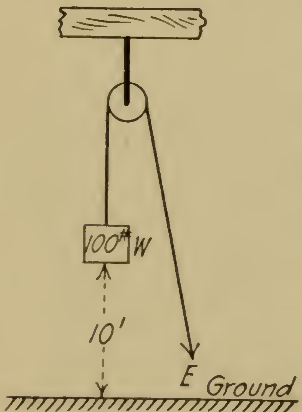

FIG. 86.—*W* has 1,000 ft.-lb. of potential energy.

Many bodies possess energy on account of their *position.* This form of fixed energy is called *potential energy.* The pile driver furnishes a good illustration. The heavy weight, or driver when released, will fall toward the earth and, on striking an object, will accomplish work. A body weighing 100 lb. and suspended 10 ft. above the earth has 1,000 ft.-lb. of potential energy (see Fig. 86). In order to elevate the body it was necessary to do 1,000 ft.-lb. of work. The potential energy possessed by any suspended body is measured by the amount of work necessary to raise the body to its position.

$$\textit{Potential energy} = \textit{Weight} \times \textit{height} = W \times h$$

Potential energy may also be due to *elasticity*. If a coiled spring, when released, is able to exert an average force of 100 lb. through a distance of 4 in., it is evident that 400 in.-lb. of work have been done. It is likewise evident that the spring must have possessed 400 in.-lb. of potential energy. The valve springs of a gasoline motor furnish a good example of potential energy due to elasticity.

$$\textit{Potential energy} = \textit{Force} \times \textit{distance} = F \times d.$$

116. Kinetic Energy.—*Kinetic energy is the energy of motion.* A rotating fly wheel or a moving projectile possesses kinetic energy. In fact, *any moving body* possesses kinetic energy, because it has the ability to do work. The same amount of work will be necessary to bring a body to rest as was necessary to set the body in motion. If a motor boat has 50,000,000 ft.-lb. of kinetic energy, 50,000,000 ft.-lb. of work will be done in bringing the boat to a stop.

$$\textit{Kinetic energy} = \frac{WV^2}{2g} \text{ ft. lb., in which } \left\{ \begin{array}{l} W = \text{weight of the body in lb.,} \\ V = \text{velocity per sec. in ft.,} \\ g = 32.16\text{, acceleration of gravity.} \end{array} \right.$$

$$\textit{Kinetic energy} = 1/2\, MV^2 \text{ ergs, in which } \left\{ \begin{array}{l} M = \text{mass of the body in grams,} \\ V = \text{velocity per sec. in cm.} \end{array} \right.$$

117. Why a Body Possesses Energy.—Every body possessed of energy has, at some time, had work done upon it. A compressed spring has potential energy, due to the fact that work was done in compressing the spring. A steam shovel, suspended above the ground, possesses potential energy, due to the fact that a certain amount of work was done upon the shovel in lifting it. Similarly, a motor cycle, coasting along a level stretch, owes its kinetic energy to the fact that work was done in imparting to it the momentum. *Work, it will be seen, consists of taking energy from one body and giving it to another body.*

118. Transformation of Energy.—If the weight shown in Fig. 86 is released, it will have 1,000 ft.-lb. of kinetic energy on striking the ground. During the fall the potential energy was being converted into kinetic energy. At any time during the downward course of the weight, the weight possessed 1,000 ft.-lb. of energy, that is, *the sum of the potential and kinetic energy was constant.* Starting with potential energy alone, we see a gradual loss of potential energy and a proportionate increase of kinetic energy until, on striking the ground, the body has entirely lost its original potential energy and possesses a like amount of kinetic energy.

Other transformations of energy may be noted such as: (1) Transformation of heat energy into mechanical energy, as in the steam engine; (2) transformation of mechanical energy into electrical energy, as in the steam-electric plant; and transformation of mechanical energy into heat energy, illustrated in stopping an automobile by means of brakes. Other examples might be given, but these are sufficient to show that one kind of energy may be replaced by another.

119. Conservation of Energy.—According to the law of conservation of energy, *the amount of energy in the universe is constant.* In other words, energy may neither be *created* nor *destroyed.* We have seen, however, that energy may be *transformed* from one kind to another. Useful energy, which disappears as such, reappears in some other form and is called *dissipated energy.* The electrical energy of an incandescent light bulb is transformed into light and heat energy. Since the heat energy of no use, it is called dissipated energy. Yet in no way has the original electrical energy been destroyed. Likewise the heat and light energy was not created; it resulted from the transformation of the electrical energy.

120. The Mechanical Equivalent of Heat.—In order to measure the amount of heat possessed by a body, a unit known as the British thermal unit is employed. *The British thermal unit (B.t.u.) is the amount of heat necessary to raise* 1 *lb. of water* 1 *degree Fahrenheit in temperature.* If 10 lb. of water are raised 4° Fahrenheit in temperature, then 40 B.t.u.

of heat energy was necessary to effect the rise. It has been found by experiment that there is a strict relation between work done and heat generated. It has been determined that 780 ft.-lb. of work always result in the appearance of 1 *B.t.u.* of heat; or, conversely, that 1 *B.t.u.* of heat will produce 780 ft.-lb. of work. This relation was discovered by James Prescott Joule,[1] in whose honor the joule was named.

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[1] James Prescott Joule (1818–1889). Famous English physicist and chemist. Determined the mechanical equivalent of heat and established the law of conservation of energy. Made many valuable experiments in electricity and magnetism.

Questions and Problems

1. Define energy. Explain why a body possesses energy.

2. What is fixed energy? Give examples.

3. What is potential energy? Give examples of potential energy due to (*a*) position; (*b*) elasticity.

4. How is the energy in a pound of coal measured?

5. Give the formulas for potential energy.

6. What is kinetic energy? Give examples.

7. Give the formulas for kinetic energy.

8. Give several illustrations of the transformation of energy.

9. State and discuss the law of conservation of energy.

10. What is meant by the mechanical equivalent of heat. Discuss fully.

11. A mine cage weighing 500 Kg. is suspended at the top of a shaft 100 m. deep. What is its potential energy with respect to the bottom of the shaft?

12. How much kinetic energy will the cage in the previous problem have on striking if the cable breaks?

13. A coiled spring, when released, exerts a pressure of 50 lb. through a distance of 3 in. What potential energy did it possess?

14. A ton pile driver drops 10 ft. What is the average resistance of the pile if it is driven down 2 in?

15. A truck weighing 2 tons is moving at the rate of 20 *m.p.h.* What force must be applied to stop it in 300 ft. if the engine is shut off?

16. What is the kinetic energy of a tug weighing 100 tons and moving at the rate of 10 *m.p.h.?* How much work must be done to bring the tug to a stop if the steam is shut off?

17. A projectile weighing 500 Kg. has a muzzle velocity of 1,000 m. per sec. What is its kinetic energy?

18. A baseball weighing 5 oz. strikes the catcher's mitt with a velocity of 40 ft. per sec. What is the kinetic energy on striking?

19. An automobile weighing 3,000 lb. is driven at the rate of 50 *m.p.h.* on a level stretch. The power is shut off just as the car strikes a 3 per cent. grade. How far up grade will it go before stopping? Assume no loss by friction.

20. A spike is being driven by a sledge. The sledge weighs 40 lb. and strikes the spike at the speed of 10 ft. per sec. If the spike is driven in 1 in. at each blow, what average resistance does it work against?

CHAPTER XVII

FRICTION

121. Friction.—*Friction is the resistance offered to the movement of one body over another.* This resistance is due to the fact that no surface is perfectly smooth. The microscope reveals to us that every body, no matter how smooth it may seem, is covered with countless small *projections.* When bodies are in contact, these projections interlock, giving rise to friction. Suppose we take as an illustration two surfaces which have been planed and polished with the utmost care. When examined under the microscope, the surfaces are found to be made up of "hills and valleys" as shown (with exaggeration) in Fig. 87. It will be seen that the projections of A sink into the depressions of B. In order to move A horizontally along B, it is necessary to lift the upper surface of A until the projections cease to interlock. Lifting a body involves *work.* Since work involves *force,* it is easy to see why force is necessary in overcoming friction.

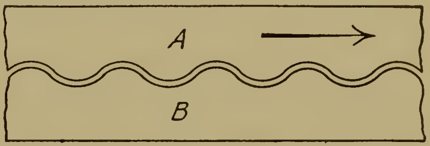

FIG. 87.—Diagram (exaggerated) showing cause of friction.

122. Advantages and Disadvantages of Friction.—It would be impossible for us to do without friction. If there was no friction, we would be unable to walk or stand; it would be almost impossible for us to pick up objects. Locomotives would be useless, as there would be no traction between the drivers and rails. Belt driven machines and friction clutches would not operate.

On the other hand, friction is a perplexing problem for the engineer. He is constantly endeavoring to eliminate it, because it impairs the efficiency of machines, resulting in wear and dissipated power. Power transmitted through spur or bevel gears is cut down markedly by friction. A worm-driven automobile, noticeable for silent running, is impaired in efficiency by the friction of the worm and worm gear. It is evident, from the above discussion, that friction is desirable in certain ways and undesirable in others.

123. Coefficient of Friction.—The fraction representing the relation between friction and pressure is known as the *coefficient of friction.*

$$\text{Coefficient of static friction} = \frac{\text{static friction}}{\text{pressure normal to surfaces}}$$

$$\text{Coefficient of kinetic friction} = \frac{\text{kinetic friction}}{\text{pressure normal to surfaces}}$$

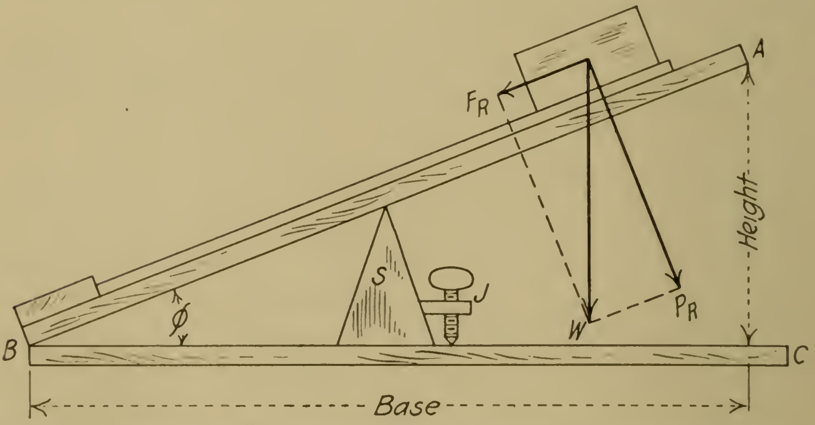

Fig. 88.—Apparatus for determining coefficient of sliding friction.

The coefficient of *sliding* friction only will be considered here and is usually spoken of simply as the coefficient of friction. It may be determined by means of the apparatus shown in Fig. 88. *ABC* is an adjustable inclined plane to which may be attached various substances such as sheet copper, leather, brake linings, etc. Suppose we wish to determine the coefficient for carbon and copper. The copper sheet is firmly attached to the upper surface of the plane and a 4 lb. carbon block is placed on the copper. The plane is now adjusted until the block *just refrains* from moving down the plane. The block is gently tapped and the angle θ slowly increased by the fine adjustment J until the carbon begins to move *slowly* and *uniformly* down the copper sheet. The coefficient of friction is equal to the *height* of the plane divided by the *base* of the plane.

$$\textit{Coefficient of friction} = \frac{\textit{height}}{\textit{base}}$$

The height and length are measured and are found to be 6 in. and 24 in. respectively. Hence the coefficient for carbon and copper will be 6/24 = .25. Since height/base equals the tangent of angle θ, it is evident that the coefficient is also equal to the tangent of angle θ (in this case 14°).

$$\textit{Coefficient of friction} = \textit{tangent of angle } \theta$$

By referring to Fig. 88, the above mathematical relations are easily explained. W, the weight of the block, may be resolved into two components: $Fr.$ or the force parallel to the plane just necessary to overcome friction and $Pr.$ the perpendicular pressure between the surfaces. The coefficient is evidently $Fr./Pr.$ By similar triangles it may be proven that $Fr.$ is proportional to AC or the height of the plane, and that $Pr.$ is proportional to BC or the base of the plane. Hence the coefficient is equal to the height/base or the tangent of angle θ.

124. Laws of Friction.—There are so many elements entering into a consideration of friction that it almost impossible to formulate any exact laws concerning it. Friction depends on materials, pressure, smoothness, amount and kind of lubrication, temperature, etc. The following laws are accurate enough for ordinary purposes.

FOR SOLIDS:

1. *Friction varies with the nature of the surfaces in contact.*
2. *Friction is proportional to the perpendicular pressure between the surfaces in contact.*
3. *Friction is not affected by the amount of the area of the surfaces in contact.*
4. *Friction decreases somewhat as the velocity increases.*

FOR FLUIDS:

1. *Except at high speeds, friction is little affected by the nature of the surfaces in contact.*
2. *Friction is independent of the pressure between the surfaces in contact.*
3. *Friction depends upon the area of contact and is proportional to it.*
4. *Friction increases with velocity and is very great at high speeds.*

123. Anti-friction Devices.—The modern machine has been greatly increased in efficiency through the employment of *anti-friction devices.* The simplest method of reducing friction is to make the surfaces in contact as smooth as possible by mechanical means, such as *planing* and *polishing.* The friction is further reduced if the surfaces are *lubricated. Bearings* are used to cut down the friction of rotating bodies. A bearing is a device by which rotating bodies are held in place. They are classed as *low, medium* or *high duty,* according to the load they are able to carry. Bearings are either *plain,* in which one surface rubs against another; *ball;* or *roller.* If a bearing is designed to take care of a load at right angles to the rotating body, it is called a *radial* bearing; if it takes care of a load *longitudinal* to the rotating body, it is called a *thrust* bearing. Many bearings are a combination of the two.

126. Plain Bearings.—The accompanying diagram (Fig. 89) shows the connecting rod bearings of a "Universal Unaflow" steam engine. The rod is made from forged steel and fitted with a heavy iron box lined with babbitt at the crank end and a bronze box at the crosshead end. Wear is taken care of by means of the adjustments shown. Babbitt is a light, whitish material and is an alloy of tin, copper and antimony. It has a low melting point and is very easy to

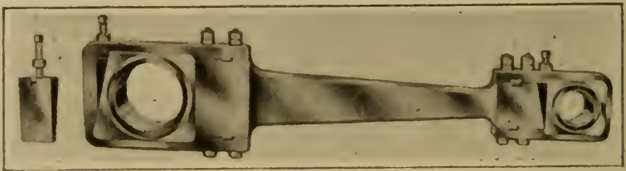

FIG. 89.—Steam engine connecting rod with plain bearings.

work. Plain bearings are used almost exclusively on the steam engine.

Figure 90 shows the bearings used on the connecting rod of a Cole "Aero-Eight" automobile and is characteristic of automobile connecting rods in general. The rod is joined to the crankshaft by a babbitt lined bearing. It is secured to the piston by a steel wrist pin forced into place and employs a bronze bushing as a bearing. Bronze outwears babbitt but is not so easily worked.

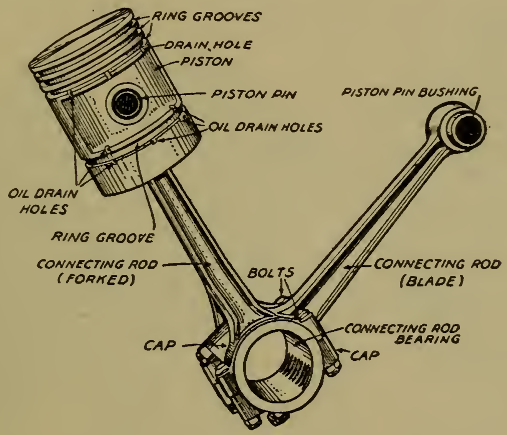

FIG. 90.—Diagram showing plain bearings used on the connecting rod of an automobile.

127. Ball Bearings.—Ball bearings are used on magnetos, electric motors and generators, automobile transmissions, airplane propellers, etc. The *cup-and-cone* bearing (Fig. 91) is designed to stand occasional end thrusts and is adjustable. The cup and cone, however, must be set at an angle which

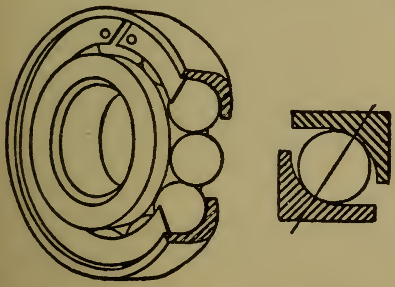

FIG. 91.—Cup-and-cone ball bearing.

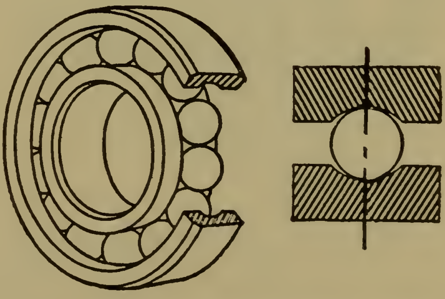

FIG. 92.—Annular ball bearing.

lessens the radial load capacity. The efficiency of this type of bearing is greatly reduced when wear occurs.

The *annular* ball bearing (Fig. 92) has a heavy vertical load capacity, but makes no provision for thrust. If thrust loads are present to any extent, thrust bearings must be used in addition. The annular type of bearing is not adjustable and must be replaced after wear. It is more correct in design than the cup-and-cone bearing and is preferred for that reason.

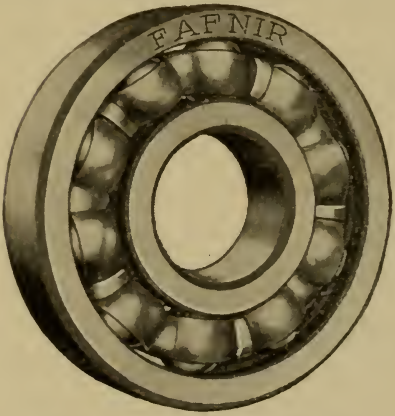

Fig. 93.—Fafnir radial ball bearing assembled.

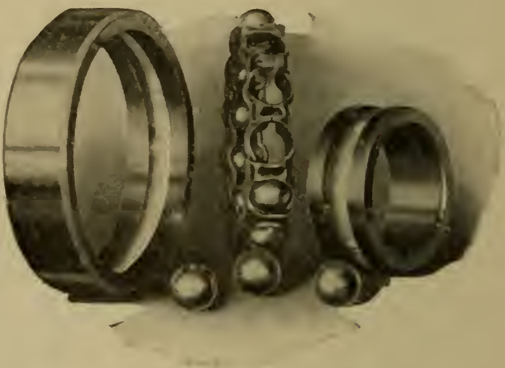

Fig. 94.—Fafnir radial ball bearing disassembled.

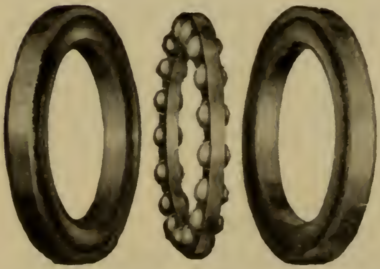

Fig. 95.—Fafnir thrust ball bearing (flat-race type) unassembled.

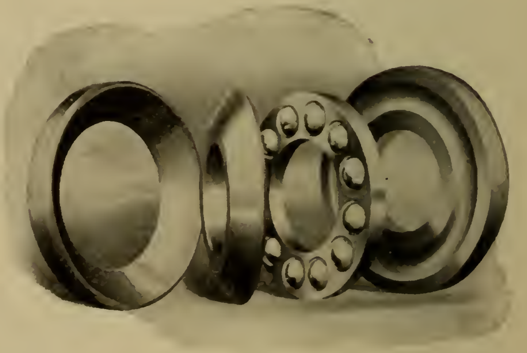

Fig. 96.—Fafnir thrust ball bearing (self-aligning type) unassembled.

Fafnir ball bearings are representative of the best and are here selected for description. The student should examine the illustrations above carefully.

Fafnir bearings are made of an alloy of high carbon, chrome steel, hardened by a special heat treatment and quenched in oil to insure proper density and hardness. The raceways are very accurately ground and the balls are guaranteed round and true to 1/10,000 of an inch.

128. Roller Bearings.—Roller bearings have proven very satisfactory, particularly for medium and heavy loads. The Hyatt and Timken bearings are selected for study on account of their wide use.

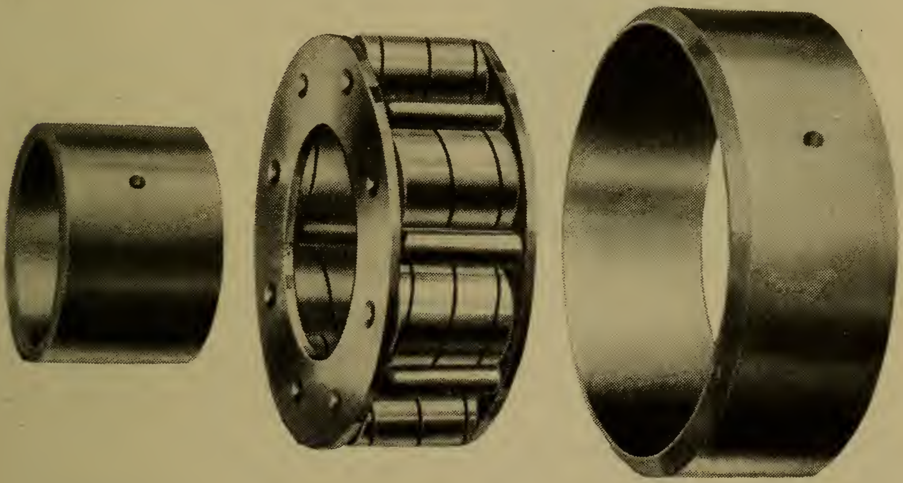

Fig. 97.—Hyatt roller bearing unassembled.

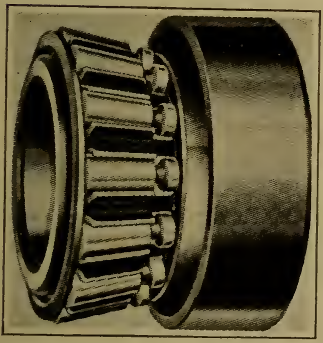

Fig. 98.—Timken roller bearing partly unassembled.

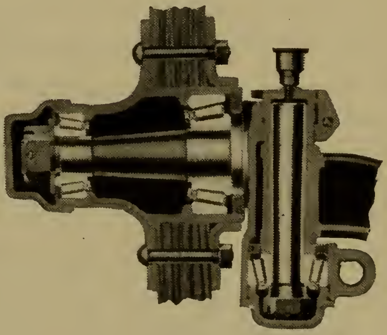

Fig. 99.—Front wheel of an automobile mounted on Timken bearings.

The Hyatt bearing (Fig. 97) is used for automobiles, mine cars, line shafts, refrigerating machines, printing presses, etc. It consists of flexible, hollow *rollers* of heat-treated alloy steel wound helically, and an *inner* and *outer race*. If shafts are sufficiently hard, the inner race may be dispensed with. The inner race is made from seamless tubing of alloy steel, carburized and heat treated. The outer race is of the same material and is either *split* or *solid*. For heavy work, the solid type should always be used. The rollers are held in place by heavy bars riveted to the end rings. The bars and rings constitute the *cage*. Hyatt bearings make no provision for thrust.

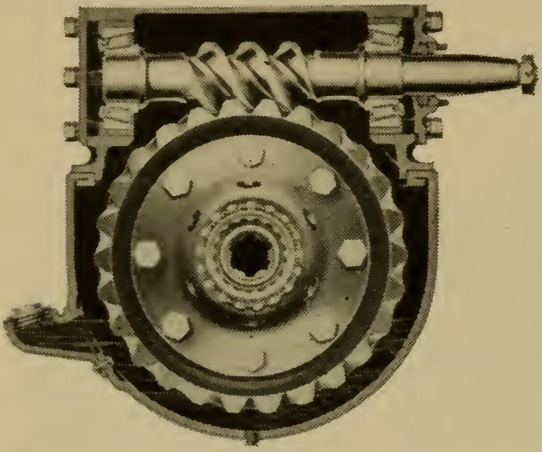

FIG. 100.—Timken bearings used on a worm-drive truck.

The Timken bearing (Fig. 98) has a *ribbed cone* of carbonized, electric steel, with *outside taper; tapered rollers* of electric alloy steel, heat-treated; a *tapered cage* or *roller retainer* of sheet steel; and a *cup* or *outer race* of electric steel, with *inside taper*. It will be observed that this bearing is a combination thrust and radial bearing; also that its peculiar construction enables wear to be taken up easily.

Timken bearings are used extensively for automobiles at points of hard service such as rear and front wheels, differential, pinion or worm and transmission. Figures 99 and 100 show installations of Timken bearings on the automobile.

129. Lubrication of Bearings.—The best lubricant for bearings is a neutral mineral oil or grease, entirely free of any acid, alkali or sulphur. Animal and vegetable oils are apt to contain acid in sufficient quantities to cause corrosion. A good lubricant will not only lessen friction, but will also protect the metallic surfaces from the action of the atmosphere and aid in the exclusion of dirt and water. A light or medium oil is generally used for high speeds, while liquid grease or heavy machine oil is used for slow speeds.

Questions and Problems

1. Define friction.

2. Show, using diagram, why force is necessary in overcoming friction.

3. Discuss the advantages and disadvantages of friction.

4. What is static friction? Kinetic friction?

5. What is meant by the coefficient of friction? Describe a method of determining it.

6. State four laws for friction between solids; four laws for fluid friction.

7. State the various methods employed in reducing friction.

8. What is a bearing? Radial bearing? Thrust bearing?

9. Describe typical plain bearings and give concrete illustrations showing where they are used. Discuss the relative advantages of babbitt and bronze.

10. Describe the ball bearing. For what kind of work is it used?

11. What is an annular bearing? Cup-and-cone bearing?

12. Describe the Hyatt roller bearing. What is the advantage of the spiral rollers?

13. Describe the Timken roller bearing. What is the distinctive feature of the Timken bearing?

14. A force of 6 lb. is necessary to draw a sled weighing 50 lb. along a horizontal surface. Find coefficient of friction and work done if the sled moves 50 ft.

15. The coefficient of friction for oak on leather is .30. What force is necessary to pull an oak block weighing 7 lb. slowly and uniformly over a level, leather surface?

16. If it takes a force of 10 lb. to slide a piece of ice across the floor and the coefficient of friction is .06, what is the weight of the ice?

17. An inclined plane has an upper surface of dry agate. The plane is adjusted until a steel block weighing 10 lb. slides slowly and uniformly down the plane. Find the coefficient of friction for steel on dry agate, if the plane is 5 ft. long and 1 ft. high.

18. The experiment was repeated with oiled agate and the coefficient of friction was found to be .107. What was the height of the plane?

19. An iron block is hauled along a level stone surface by a force of 200 lb. acting at an angle of 5° to the horizontal. If the coefficient of friction is .50, what is the weight of the block?

CHAPTER XVIII

SIMPLE MACHINES

130. The Machine.—*The machine is a mechanical device designed to do work advantageously.* A machine does not possess energy in itself, but must receive energy from some outside source. The original energy, after various transformations and dissipations, will be delivered in part to some special place where the work is to be done. It should be borne in mind that *no energy is ever destroyed,* but simply disappears as useful energy. The great problem in connection with machines is to reduce all operating losses as far as possible; that is, to work for a higher efficiency by causing the output to approach the input more closely.

131. Simple Machines.—Simple machines are divided into *six* general classes, according to the principle upon which they work; namely, the *lever, pulley, wheel and axle, inclined plane, screw* and *wedge.* As will be seen later, there are in reality only *two* different classes, namely, the *lever* and *inclined plane.* The pulley and wheel and axle are modified levers, and the screw and wedge are modified inclined planes. All machines operate on the principle of the lever or inclined plane or a combination of the two. It will be assumed, in studying simple machines, that *no friction is present* and that the efficiency is therefore 100 per cent.

132. Important Definitions.—In discussing machines, we shall have occasion to refer repeatedly to *input, output, efficiency, velocity ratio* and *mechanical advantage.* A proper study of machines depends upon a thorough understanding of the above terms.

Input.—Input is the energy received by a machine from some outside source.

Output.—Output is the energy which a machine is capable of delivering and is always less than the input.

Efficiency.—Efficiency is the ratio of the output to the input. It is customary to reduce the decimal thus obtained to per cent.

$$\text{Efficiency} = \frac{\text{output}}{\text{input}}$$

Velocity Ratio.—Velocity ratio is the distance through which the driving force acts divided by the distance through which the resisting force acts in the same time.

Mechanical Advantage.—Mechanical advantage is the ratio of the resisting force or load to the driving force or effort.

$$M.A. = \frac{\text{resisting force}}{\text{driving force}} = \frac{R}{E}$$

133. Law of Frictionless Machines.—Provided there was no friction, the following law would apply to all machines,

The driving force (E) × *the distance* (d_1) *through which it acts = the resisting force* (R) × *the distance* (d_2) *through which it acts in the same time.*

$$E \times d_1 = R \times d_2$$

134. General Law for All Machines.—Since friction can never be eliminated entirely, for practical purposes the above law should be amended to read,

The driving force (E) × *the distance* (d_1) *through which it acts × the efficiency* (*Effic.*) *= the resisting force* (R) × *the distance* (d_2) *through which it acts in the same time.*

$$E \times d_1 \times \text{Effic.} = R \times d_2$$

Since *input* is equal to *output plus the energy used in overcoming friction*, the law may also be stated,

The driving force (E) × *the distance* (d_1) *through which it acts = the resisting force* (R) × *the distance* (d_2) *through which it acts in the same time + friction* (*Fr.*) × *the distance* (d_3) *through which it acts also in the same time.*

$$E \times d_1 = (R \times d_2) + (Fr. \times d_3)$$

It is essential that the student should thoroughly understand the laws given in this paragraph. These laws apply to *all* machines (frictionless or non-frictionless). Any subsequent "laws" relating to machines will be found to be simply special applications of the *general law*.

General Questions Relating to Machines

1. What is a machine? What is the source of energy in a machine?

2. What are the six simple machines? Into what two ultimate classes may they be divided?

3. What is meant by input, output, efficiency, velocity ratio, mechanical advantage?

4. What is the law of "frictionless" machines? Is perpetual motion possible? Why?

5. What is the "general law" of all machines? State the law in two different ways. Show that this law applies to "frictionless" machines.

6. How may the efficiency of a machine be increased?

135. The Lever.[1]—*The lever is a rigid rod or bar designed to rotate about a fixed point called the fulcrum.* Unless otherwise noted, levers will be considered weightless. Levers are divided into three classes, according to the relative positions of the effort, resistance and fulcrum. A lever will be in equilibrium when,

The effort (E) × *the perpendicular distance* (d_1) *to the fulcrum = the resistance* (R) × *the perpendicular distance* (d_2) *to the fulcrum.*

$$E \times d_1 = R \times d_2$$

136. The First Class Lever.—The first class lever is illustrated by a crow bar. A heavy weight may be raised by the application of a relatively small force. An examination of Fig. 101 shows that the fulcrum is between the effort and

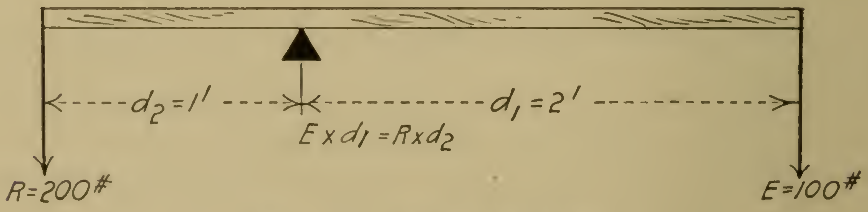

Fig. 101.—First class lever.

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[1] It is suggested that Chap. X be reviewed at this point.

resistance and that speed is sacrificed for force. In case of rotation, the output will be equal to the input and the *v.r.* and *m.a.* will be numerically the same.

137. The Second Class Lever.—The second class lever is illustrated by a wheelbarrow. An examination of Fig. 102 shows that the resistance is between the fulcrum and effort and that speed is sacrificed for force. In case of rotation, the output will be equal to the input and the *v.r.* and *m.a.* will be numerically the same.

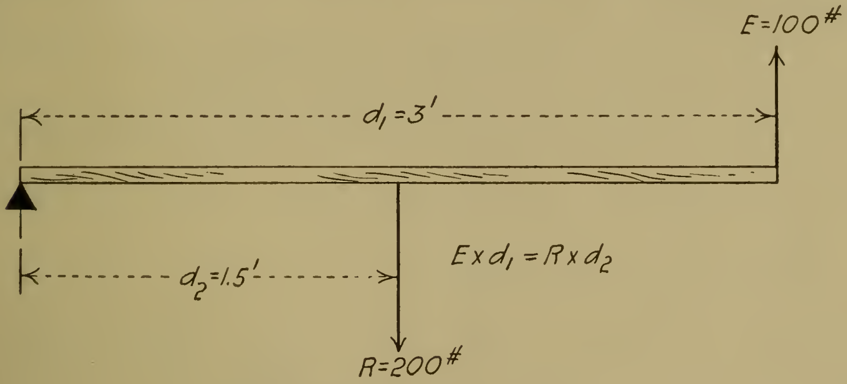

FIG. 102.—Second class lever.

138. The Third Class Lever.—The third class lever is illustrated by the fishing rod. An examination of Fig. 103 shows that the effort is between the fulcrum and the resistance and that force is sacrificed for speed. In case of rotation, the

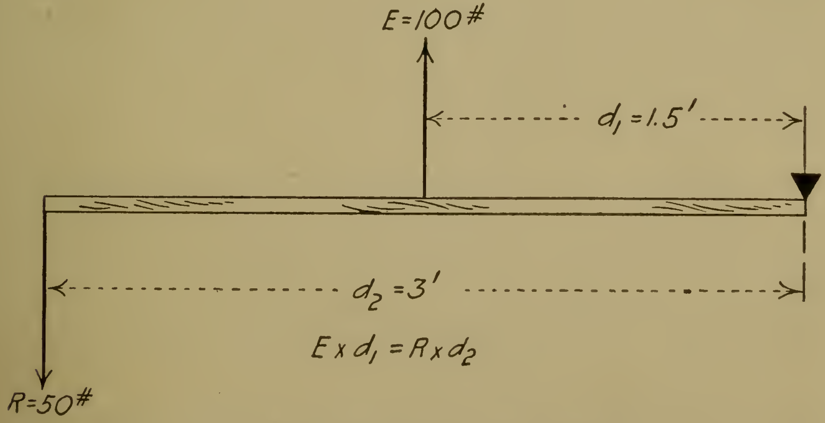

FIG. 103.—Third class lever.

output will be equal to the input and the *v.r.* and *m.a.* will be numerically the same.

Questions and Problems Relating to the Lever

1. What is a lever? Describe the different classes of levers and give an example of each.

2. State the law of "frictionless," "weightless" levers. Show that this law is an application of the general law of machines.

3. In case the lever is not considered weightless, how would the above law read?

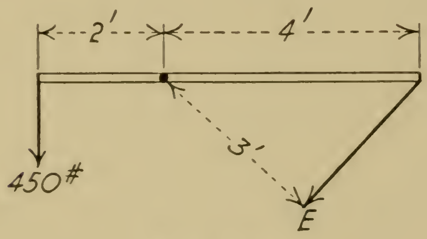

FIG. 104.

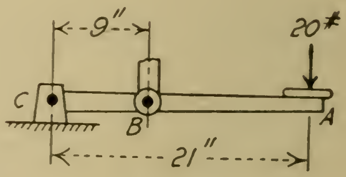

FIG. 105.

4. State the class of lever illustrated in the following cases: (*a*) drawing a nail with a claw hammer; (*b*) rowing a boat; (*c*) turning a grindstone by foot-power; (*d*) using a pair of shears; (*e*) lifting a pail of water; (*f*) moving the spark control of an automobile; (*g*) cranking an automobile.

5. Determine the velocity ratio and mechanical advantage in Figs. 101, 102 and 103; also the input and output. Assume a rotation of 360°.

6. A first class lever is 10 ft. long. Where must the fulcrum be placed in order that a weight of 100 lb. suspended at one end may be balanced by a weight of 50 lb. at the other end?

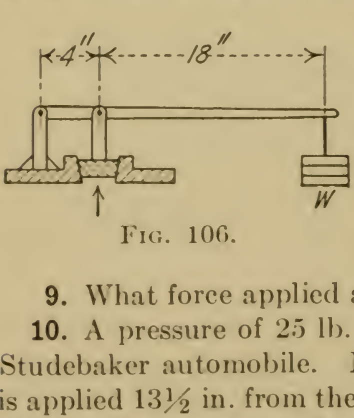

FIG. 106.

7. A second class lever is 10 ft. long. Where must a weight of 100 lb. be placed in order to be balanced by a weight of 50 lb. suspended at the end of the lever?

8. A third class lever is 10 ft. long. What force applied 6 ft. from the fulcrum will balance a weight of 100 lb. at the opposite end?

9. What force applied at *E* (Fig. 104) will produce equilibrium?

10. A pressure of 25 lb. is applied to the emergency brake lever of a Studebaker automobile. If the resistance arm is $2\frac{3}{4}$ in. and the effort is applied $13\frac{1}{2}$ in. from the fulcrum, what is the tension in the brake rod? What is the *m.a.? v.r.?*

11. Find the tension in rod *B* for the treadle as shown in Fig. 105. What force acts on the pin at *C*? What is the *m.a.? v.r.?*

12. Figure 106 represents a lever safety valve used on stationary steam engines. The valve is 2 in. in diameter and weighs 3 lb. Assuming the lever to be weightless, what weight must be suspended at *W* so that the valve will "blow" at a pressure of 175 lb. per sq. in.?

139. Pulleys.—*The pulley is a wheel (generally of wood or metal) having a grooved circumference and able to rotate freely about a fixed axis at its center.* If several pulleys are combined along the same axis in the same sheath which is fixed, and if a like combination which is movable is joined to it by means of a rope or chain, we have what is known as a *block and tackle.* In principle the pulley is a rotating lever. It may bring about a gain in force or an advantage of direction. Pulleys are usually arranged horizontally in the sheath; for convenience, the vertical arrangement is used here.

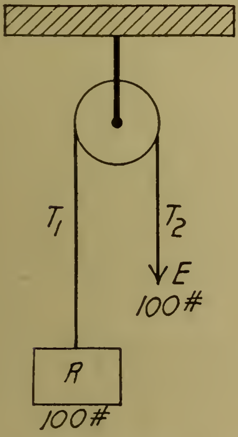

FIG. 107.—Single fixed pulley.

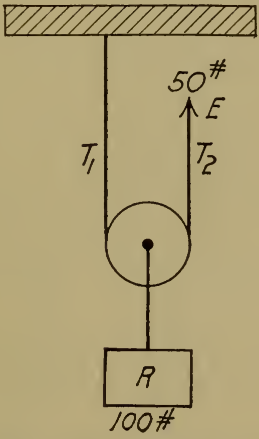

FIG. 108.—Single movable pulley.

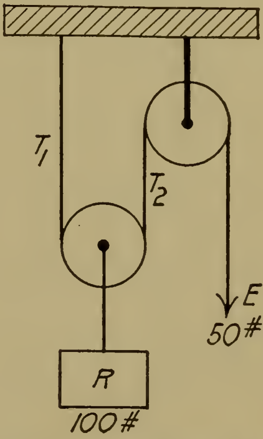

FIG. 109.—Single fixed and single movable pulley.

The *single fixed pulley* (Fig. 107) has an advantage of direction only, *E* and *R* being equal since the tensions T_1 and T_2 are 100 lb. each. The *m.a.* is 100/100 or 1. *E* and *R* have the same speed in case of rotation; hence the *v.r.* is 1.

The single movable pulley (Fig. 108) is used when a gain in force is desired. The supporting tensions T_1 and T_2 are 50 lb. each and the *m.a.* is 100/50 or 2. Since *E* has twice the velocity of *R*, the *v.r.* will be 2.

A single fixed pulley is generally used with a *single movable pulley* (Fig. 109). The extra pulley enables the effort to be applied more conveniently. The *m.a.* and *v.r.* are the same as in the previous case.

Figure 110 shows another arrangement of a *single fixed* and *single movable pulley*. The supporting tensions T_1 and T_2 are 50 lb. each and the *m.a.* is 100/50 or 2. E will have twice the speed of R and the *v.r.* will be 2.

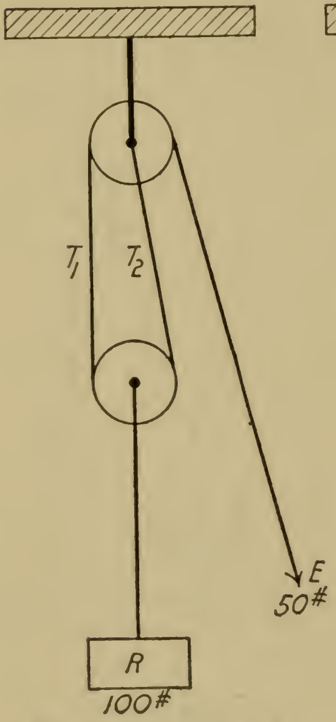

Fig. 110.—Single fixed and single movable pulley.

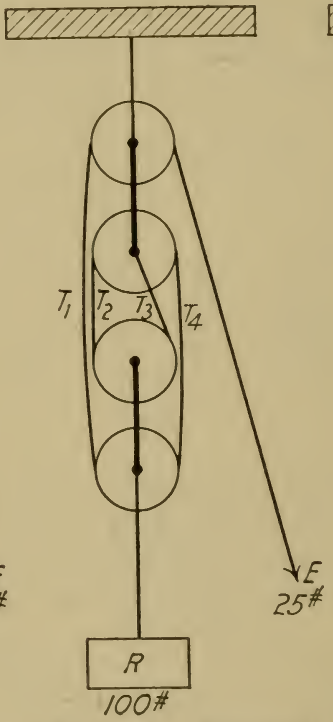

Fig. 111.—Two fixed and two movable pulleys.

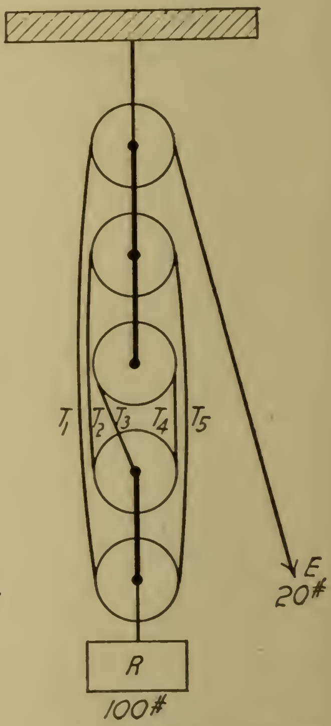

Fig. 112.—Three fixed and two movable pulleys.

Figure 111 represents *two fixed* and *two movable pulleys*. The supporting tensions T_1, T_2, T_3 and T_4 are 25 lb. each and the *m.a.* is 100/25 or 4. The *v.r.* will also be 4.

Figure 112 represents *three fixed* and *two movable pulleys*. The supporting tensions T_1, T_2, T_3, T_4 and T_5 are 20 lb. each and the *m.a.* is 100/20 or 5. The *v.r.* will also be 5.

From the above illustrations it is evident that the effort required to lift a load by means of frictionless pulleys will be equal to the resisting load divided by the number of supporting strands.

$$\textit{Effort to lift} = \frac{\textit{resisting load}}{\textit{number of supporting strands}} = \frac{R}{N}$$

Questions and Problems Relating to the Pulley

1. Define a pulley. What is a block and tackle? How are commercial pulleys arranged in the sheath? Upon what principle does the pulley operate?

2. For what purpose is a single fixed pulley used? Single movable pulley?

3. What is the relation between the *effort*, *resisting load* and *number of supporting strands?* Show that this is a special application of the general law of machines.

4. A single fixed pulley lifts a load of 200 lb. What effort will be required? What is the *m.a?* The *v.r?*

5. A single movable pulley bears a load of 300 lb. What effort will be required? What is the *m.a?* The *v.r?*

6. Design systems of pulleys with mechanical advantages of 1, 2, 4 and 5.

7. A 1,000 lb. casting is to be loaded into a truck. Design a system of pulleys to do the work, assuming that the rope will break at any tension over 150 lb.

8. An "I" beam is being dragged along the ground by means of a single fixed and single movable pulley. The fixed pulley is attached to a tree and the movable pulley to the beam. If three men are pulling with a force of 50 lb. each, what force is exerted (*a*) on the beam? (*b*) On the tree? What is the tension in each strand?

140. The Wheel and Axle.—The wheel and axle (Fig. 113) works on the principle of a first class lever. The effort (E), applied tangentially to the rim of the wheel, will produce a rotation of both wheel and axle. E will descend and R will rise. Representing the radius of the wheel by r_1 and the radius of the axle by r_2, it is evident that $E \times 2\pi r_1 = R \times 2\pi r_2$, and that $E = \frac{R \times 2\pi r_2}{2\pi r_1} = R \times \frac{r_2}{r_1}$.

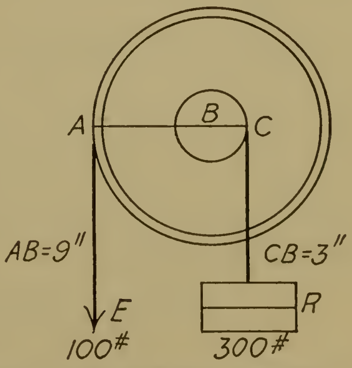

FIG. 113.—Wheel and axle.

In Fig. 113, r_1 is 9 in. and r_2 is 3 in. Hence the effort necessary to lift the load of 300 lb. is $300 \times \frac{3}{9}$ or 100 lb. The *m.a.* is 3 and the *v.r.* is 3.

Questions and Problems Relating to the Wheel and Axle

1. Describe the wheel and axle and state the purpose for which it is used.

2. State the mathematical relation of the effort, resistance, radius of the wheel and radius of the axle.

3. Show that the above relation is an application of the general law of machines.

4. The diameters of a wheel and axle are 24 in. and 4 in. respectively. What load may be lifted by an applied force of 50 lb.?

5. Compute the output and input in problem 4, assuming a rotation of 720 degrees. Also find the *m.a.* and *v.r.*

6. The *m.a.* of a wheel and axle is 10 and the load to be raised is 200 lb. If the diameter of the axle is 5 in., what is the diameter of the wheel?

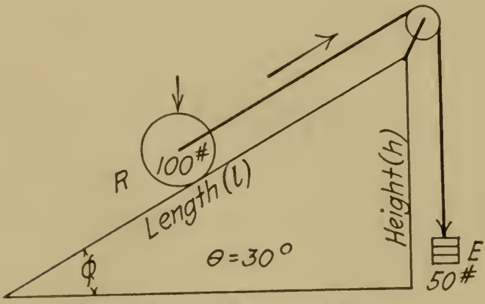

Fig. 114.—Inclined plane.

141. The Inclined Plane. The inclined plane (Fig. 114) is a block whose upper surface makes an angle of less than 90° with the horizontal. It is used to raise heavy loads, such as rolling a barrel of sugar up into a doorway by means of a plank. The effort required will depend on the slope of the plane. According to the general law of machines, the effort (E) × the length (l) of the plane = the resistance (R) × the height (h) of the plane.

$$E \times l = R \times h \text{ or } E = R \times \frac{h}{l} = R \times \sin\theta.$$

In the accompanying diagram, the plane is inclined at an angle of 30° to the horizontal and is 10 ft. long and 5 ft. high. An effort of 50 lb. will be necessary to move the weight of 100 lb. up the plane. The *m.a.* is 2 and the *v.r.* is 2.

Questions and Problems Relating to the Inclined Plane

1. What is an inclined plane? For what purpose is it used?

2. What relation exists between E, R, h and l? Between E, R and $\sin \theta$? Show how these relations are derived.

3. An inclined plane is 20 ft. long and 2 ft. high. How heavy a load can be lifted by a force of 100 lb. applied parallel to the plane? How much work is done upon the load and how much work is done by the force if the load travels the length of the plane?

4. A plane is inclined at an angle of 45°. What weight may be lifted by a force of 50 lb. acting parallel to the plane?

5. An automobile weighing 3,000 lb. is being towed up a 2 per cent. grade. Neglecting friction, what is the tension of the tow rope?

142. The Screw.—The jack screw (Fig. 115) is a modified inclined plane. A piece of paper cut into the shape of an inclined plane and wound around a pencil will represent the threads. The jack screw is used for such purposes as raising buildings and will not reverse when the applied force is removed. Assuming a complete rotation of the hand lever, it follows that the effort $(E) \times 2\pi r =$ the resistance $(R) \times$ the lead of the screw. The *lead* is the distance the screw advances during one rotation. For single-thread screws it is the same as the *pitch* (distance between two adjacent threads).

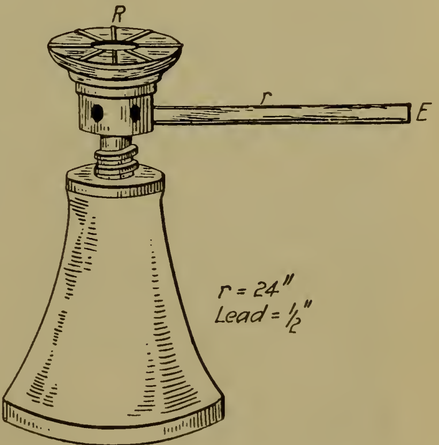

FIG. 115.—Jack screw.

$$E \times 2\pi r = R \times \mathit{lead\ of\ screw}$$

In Fig. 115, the radius[1] of the hand lever is 2 ft. and the lead is ½ in. If the load (including the moving part of the jack) is 1,000 lb., the effort to lift is found as follows:

$$E = \frac{R \times \mathit{lead}}{2\pi r} = \frac{1{,}000 \times \frac{1}{2}}{2 \times \pi \times 24} = 3.31 \text{ lb.}$$

The *m.a.* is 302.1 and the *v.r.* is 302.1.

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[1] Radius of the hand lever is measured from the center of the jack to the point where the effort is applied.

Questions and Problems Relating to the Screw

1. Describe the jack screw. For what purpose is it used?

2. Why does the jack screw not reverse?

3. What is meant by the lead of a screw? Pitch?

4. A jack screw has 4 threads to the inch. If the radius of the hand lever is 3 ft., what load may be lifted by a force of 75 lb. applied at the extremity of the lever? What is the *m.a*? The *v.r*?

5. A small building weighing 8,000 lb. is being raised by means of 4 jacks, one at each corner. If the radius of the hand lever is 24 in. and the pitch of the threads is ¼ in., what effort is necessary at the extremity of each lever. What is the *m.a.* and *v.r.* of each jack?

143. The Wedge.—The wedge (Fig. 116) is simply two inclined planes laid base to base. It is used in splitting timbers and rocks, launching ships, raising large weights through short distances, etc. All cutting tools are wedges.

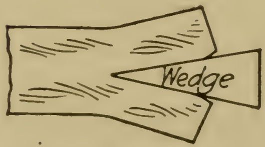

Fig. 116.—Wedge.

In actual practice, friction is such an uncertain quantity, that any law in regard to the wedge is only a poor approximation.

Questions and Problems Relating to the Wedge

1. Describe the wedge. For what purpose is it used?

2. In splitting a piece of very hard timber would you use a wedge of large or small angle? Explain.

3. In actual practice, the law of the wedge is only approximate. Why?

CHAPTER XIX

PRACTICAL STUDY OF MACHINES

144. Efficiency.—It is assumed that the student has acquired, by this time, a satisfactory knowledge of the so-called *simple* machines. Hereafter, machines will be discussed from a *practical* point of view. It is impossible, in this small volume, to examine many of the machines in common use. Those selected, however, will be typical and furnish an excellent background for further study.

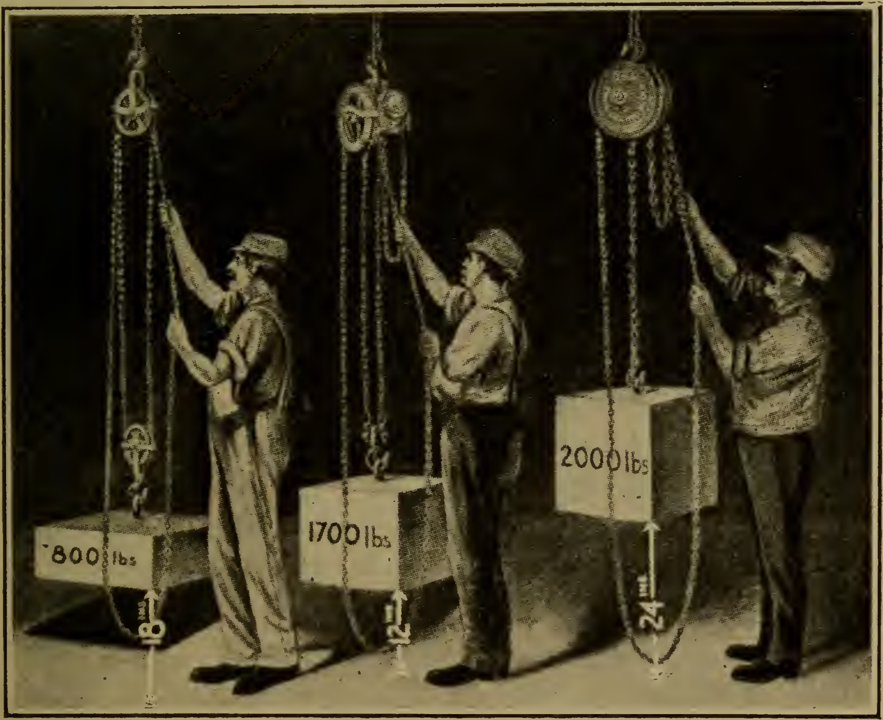

FIG. 117.—Comparison of a Yale differential, screw-geared and spur-geared chain block.

In Chap. 18, the general law of machines is stated:

$$E \times d_1 \times Effic. = R \times d_2$$

Since d_1/d_2 is equal to the velocity ratio, the law may also be stated:

$$E \times V.R. \times Effic. = R \times 1$$

Thus, to find the input of a machine, determine the velocity ratio and multiply it by the effort. The output will be equal to the resistance times 1 or, simply, the load. The above method gives the *relative* input and output and is independent of the actual distance covered by E and R. *It is suggested that all problems be solved according to this method.*

145. Chain Blocks.—As a hoisting device, the *chain block* is universally used. It is almost indispensable in machine shops, factories, warehouses, etc., where heavy loads must be lifted frequently. There are three general types in common use: the *differential* block; the *screw-geared* block; and the *spur-geared block.*

Figure 117 shows the Yale *differential, screw-geared* and *spur-geared* chain blocks of one ton capacity. The picture shows the maximum load that each man can comfortably lift and the distance through which the load can be lifted in 30 sec. It is assumed that each man pulls 82 lb. The student will observe that the spurgeared block has an advantage both of speed and efficiency over the other two.

146. Differential Chain Block.—The *differential* chain block employs two sheaves of slightly different diameter in the upper block and one sheave in the lower block. The sheaves in the upper block are cast together. Over these sheaves runs an endless hand chain. Pockets along the rims of the upper sheaves prevent slippage. When the effort is removed, the friction of the blocks is sufficient to restrain the load from running back. The differential is simple, cheap and reliable, but has not the durability or efficiency of the screw-geared or spur-geared block.

The velocity ratio of the differential is determined as follows. Referring to Fig. 118 and assuming that the upper sheaves make one revolution, E then moves a distance of $2\pi R$. Side B of the chain loop is raised $2\pi R$, but side A is lowered $2\pi r$

as the chain unwinds. The loop AB is therefore shortened $2\pi R - 2\pi r$ or $2\pi(R - r)$. The load is raised only half this distance or $\pi\ (R - r)$. Thus the effort distance divided by the load distance equals $2R/R - r$.

$$\textit{Velocity ratio for differential} = \frac{2R}{R - r}.$$

Since R and r are proportional respectively to the number of chain pockets in the larger and smaller sheaves of the upper block, it is suggested that these values be substituted for R and r in the above equation. This method eliminates any error in measurement.

In conducting a laboratory study of the differential, the velocity ratio is first determined. This is done by counting the chain pockets in the upper sheaves and substituting these values in the formula given above. The calculated velocity ratio is checked by finding the relative distances moved by the effort and load.

Next it determined, by means of a spring balance, the effort necessary to run the machine unloaded. A load of 50 lb. is now suspended from the load hook and the effort to lift recorded. The load is increased 50 lb. at a time and the corresponding efforts to lift taken in each case.

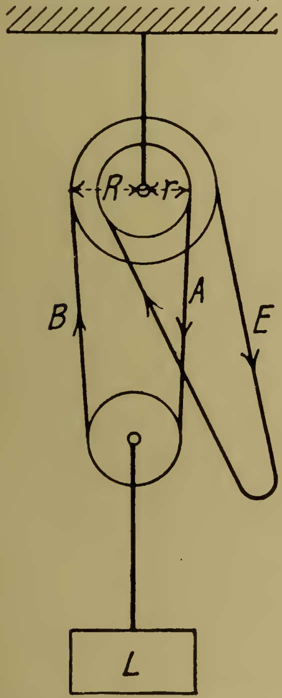

FIG. 118.—Differential chain block.

The following figures were submitted by two students. The chain block (quarter-ton capacity) was manufactured by the Chisholm and Moore Mfg. Co., Cleveland, Ohio.

VELOCITY RATIO

(*a*) Chain pockets in larger pulley of upper block = 9.

(*b*) Chain pockets in smaller pulley of upper block = 8.

(*c*) Computed velocity ratio $= \frac{2 \times 9}{9 - 8} = 18.$

(*d*) Actual velocity ratio (check),

$$\frac{\text{Distance effort travels}}{\text{Distance load travels}} = \frac{108 \text{ in.}}{6 \text{ in.}} = 18.$$

EFFICIENCY

Load in lb.	Effort to lift in lb.	Velocity ratio	Input in ft. lb.	Output in ft. lb.	Efficiency in per cent.
0	2	18	36	0	0
50	11	18	198	50	25.3
100	18	18	324	100	30.8
150	26	18	468	150	32.0
200	34	18	612	200	32.6
250	43	18	774	250	32.3
300	51	18	918	300	32.6

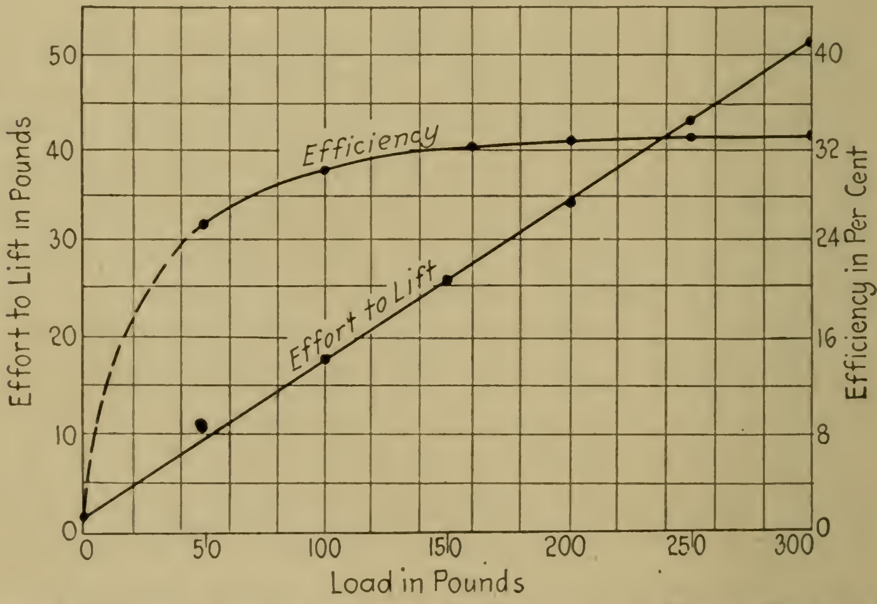

FIG. 119.—Graph showing relation of efficiency and lifting effort to load for the differential chain block.

Figure 119 is a graph showing the relation of the *driving effort* and *efficiency* to the *load*. It is customary to locate the loads along the "*x*" or horizontal axis and the efforts and efficiencies along the "*y*" or vertical axis. This graph is typical for machines and should be thoroughly understood by the student. The load-effort curve starts above zero, as some effort is required to drive the hoist unloaded. The efficiency curve always has its origin at zero, since the efficiency at zero load must necessarily be zero. It will be observed that *the* *effort is directly proportional to the load* and that *the efficiency rises with the load to about* 32 *per cent. and then remains practically constant.*

145. Screw-geared Chain Block.—The *screw-geared* block is light, compact and especially adapted to portable work. It is cheaper than the *spur-geared,* although it does not possess the speed of the latter. It depends upon the *worm* and *worm wheel* for its mechanical advantage (See Fig. 120). Effort is applied by means of a hand chain over a sheave having pockets for the chain links. This sheave is a unit with the worm shaft which directly operates the worm wheel. The worm wheel in turn rotates the load sheaves. The worm and worm wheel are of steel and bronze respectively. Parts subject to friction run in oil, insuring proper lubrication. The block may be reversed but will not "run down."

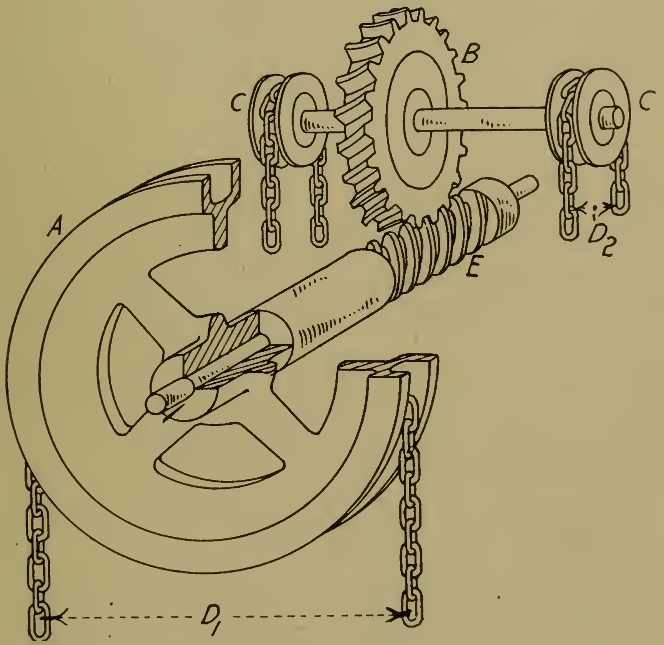

FIG. 120.—Working mechanism of a Yale screw-geared chain block.

To compute the velocity ratio, the diameter of the hand wheel and the diameter of the load sheaves is first determined. The diameter (D_1) of the hand wheel is equal to the distance between the mid-points of the chain running around it. The diameter (D_2) of the load sheaves is determined in a similar manner. Next the number (N) of teeth in the worm wheel is determined by counting the number of revolutions of A required to rotate C once.

$$\textit{Velocity ratio for screw-geared block} = \frac{D_1}{D_2} \times N.$$

In the laboratory, the velocity ratio is found as described above and checked by noting how far the hand chain moves while the load chain moves 1 ft.

Next the effort to drive the block unloaded is determined by a spring balance. Various loads are now suspended from the load hook and the corresponding efforts to lift recorded.

The following test of a Yale block was made by two students.

VELOCITY RATIO

(*a*) Diameter of hand wheel (D_1) = 5.25 in.
(*b*) Diameter of load sheaves (D_2) = 2.75 in.
(*c*) Number of revolutions of A to one of C = 20.
(*d*) Calculated velocity ratio $= \frac{D1}{D2} \times N = \frac{5.25}{2.75} \times 20 = 38.2.$
(*e*) Distance moved by hand chain = 456 in.
(*f*) Distance moved by load hook = 12 in.
(*g*) Actual velocity ratio (check) $= \frac{456}{12} = 38.$

EFFICIENCY

Load in lb.	Effort to lift in lb.	Velocity ratio.	Input in ft.-lb.	Output in ft.-lb.	Efficiency in per cent.
0	1	38	38	0	0
55	4	38	152	55	36.1
105	7	38	266	105	39.8
155	10	38	380	155	40.7
205	13	38	494	205	41.5
255	16	38	608	255	41.9

Figure 121 is a graph showing the relation of *effort* and *efficiency* to the *load*. An examination of the graph shows that *the effort is directly proportional to the load* and that *the effi-*

ciency rises with the load, becoming nearly constant around 41 *per cent.* Note that the efficiency curve starts at zero and that the load-effort curve starts above zero.

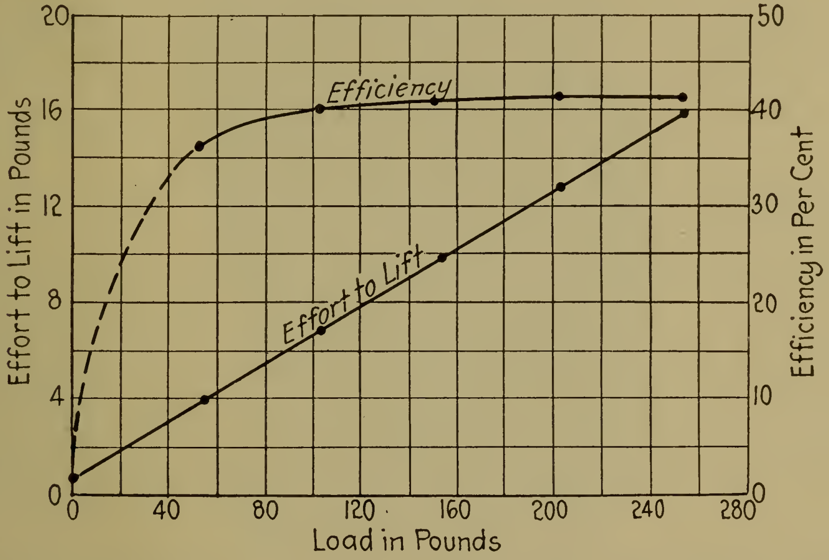

FIG. 121.—Graph showing relation of efficiency and lifting effort to load for the screw-geared chain block.

148. Spur-geared Chain Block.—The Yale *spur-geared* block is very efficient, frictional losses being reduced to a minimum. It is made for capacities of from ¼ ton to 40 tons. One man pulling 82 lb. on the hand chain can lift one ton. The lowering of the load is effected by an automatic brake mechanism. Referring to Fig. 122, it will be seen that the block employs *spur gears* based on the principle of the *planetary system.* Movement of the hand chain rotates pinion A. The pinion transmits its energy to two intermediate gears (B and B) diametrically opposed. The intermediate gears mesh with the large internal gear D, causing a revolution of the pinion cage E to which the load sheave F is attached. The design of the block distributes the pressure equally and tends to prevent wear in the bearings.

149. Chain-drive Bicycle.—The *bicycle* is a *speed* machine, effort being sacrificed in order to obtain a high velocity for the rear wheel. It is evident that both the velocity ratio and

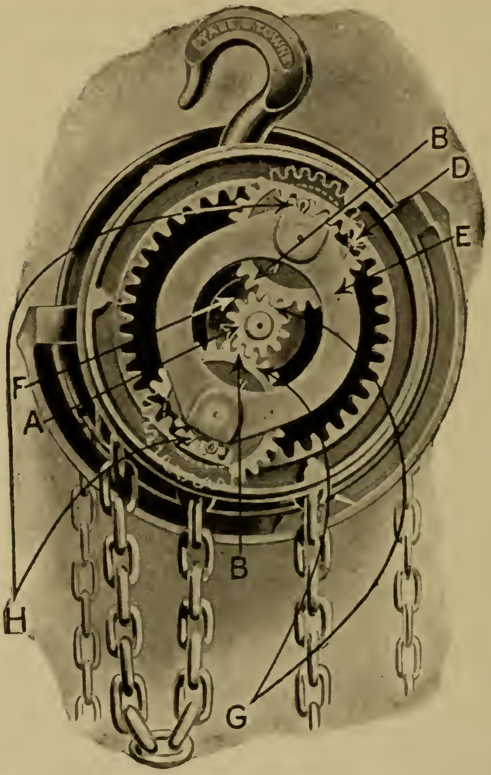

FIG. 122.—Working mechanism of a Yale spur-geared chain block.

mechanical advantage will be less than 1. The bicycle in Fig. 123 is intended for practical study. It is firmly mounted

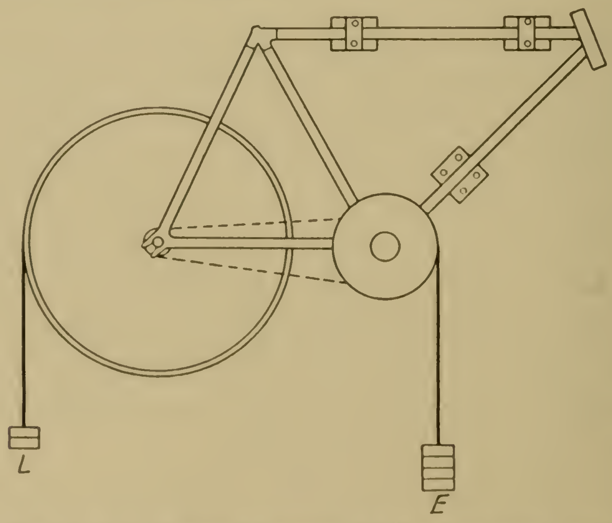

FIG. 123.—Bicycle mounted for laboratory test.

and the pedals have been replaced by a wooden pulley equal in radius to the length of the pedals. Thus the efforts may be applied conveniently by means of a stout cord and a scale pan. The loads are suspended from the rear wheel in a similar manner.

In a practical test, the velocity ratio is first calculated. The circumference of the driving and driven wheel are determined and the number of teeth in the front and rear sprockets.

$$V.r.\ for\ bicycle = \frac{circumference\ wooden\ pulley}{circumference\ rear\ wheel} \times \frac{teeth\ rear\ sprocket}{teeth\ front\ sprocket}.$$

The velocity ratio is checked by finding the distance the effort travels while the load travels 1 ft.

Next it is determined how much weight must be applied to the driving pulley to run the bicycle unloaded. Various weights are suspended from the rear wheel and the corresponding efforts to lift found.

VELOCITY RATIO

(*a*) Circumference of driving pulley = 47 in.
(*b*) Circumference of rear wheel = 77 in.
(*c*) Teeth on rear sprocket = 8.
(*d*) Teeth on front sprocket = 24.
(*e*) Distance effort travels while load travels 36 in. = 7.34 in.
(*f*) Computed velocity ratio = 47/77 × 8/24 = .204.
(*g*) Actual velocity ratio = 7.34/36 = .204.

EFFICIENCY

Load in lb.	Effort to lift in lb.	Velocity ratio.	Input in ft.-lb.	Output in ft.-lb.	Efficiency in per cent.
0	0.13	0.204	0.026	0	0
0.25	1.37	0.204	0.279	0.25	89.6
0.50	2.62	0.204	0.538	0.50	92.9
1.00	5.12	0.204	1.044	1.00	95.8
2.00	10.12	0.204	2.064	2.00	96.9
4.00	20.12	0.204	4.104	4.00	97.4
6.00	30.20	0.204	6.160	6.00	97.4

Figure 124 is a graph showing the relation of *effort* and *efficiency* to *load* for the bicycle. The load-effort line begins slightly above zero, indicating that the amount of friction is very small as compared with the machines previously studied in this chapter. It is evident that *the effort is directly proportional to the load* and that *the efficiency increases with the load to a little over* 97 *per cent. and then remains constant.*

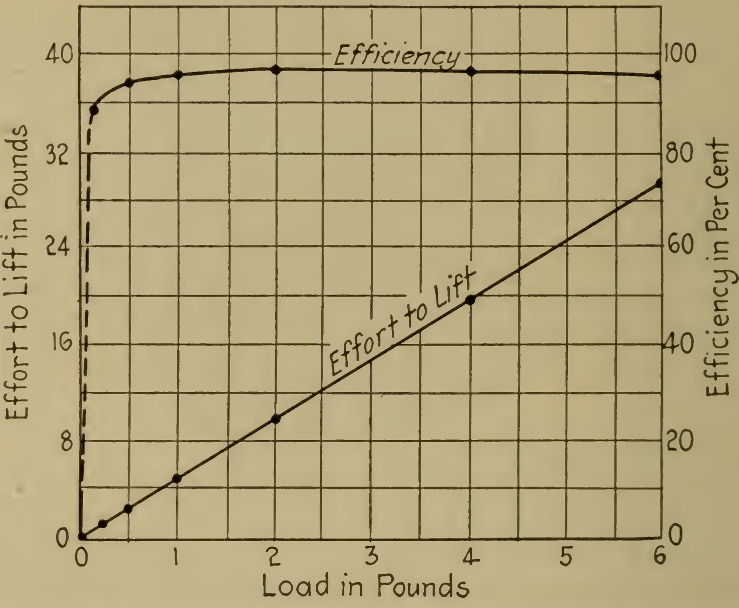

FIG. 124.—Graph showing relation of efficiency and lifting effort to load for the bicycle.

150. The Jack Screw.—The principle of the jack screw was discussed in Chap. 18. In order to approach actual working conditions for an efficiency test, the apparatus shown in Fig. 125 is recommended. Sufficient loads may thus be obtained to make the test very practical.

An examination of the above diagram shows that the hand lever has been replaced by a grooved wheel equal in radius to the length of the original torque rod. Various weights are suspended from *D* and the corresponding efforts to rotate the wheel are determined by means of a spring balance attached to a stout cord running around the wheel. The experimental work is conducted as follows.

First the velocity ratio is determined. This is found by dividing the circumference of the wheel by the lead of the screw.

$$\textit{Velocity ratio for jack screw} = \frac{\textit{circumference of driving wheel}}{\textit{lead of screw}}.$$

Next the weight and center of gravity of the beam is found; also the weight of the moving part of the jack. It is suggested that these figures be recorded permanently on the beam for quick reference and that yard sticks be attached to the beam to facilitate the measurement of distances. The beam is levelled and 50 lb. is suspended from D. The effort to rotate the wheel slowly is found by means of a spring balance. The suspended weight is increased 50 lb. at a time and the efforts to lift recorded in each case; also the distances d_1, d_2 and d_3 (See Fig. 126). The load may also be varied by moving the jack along the beam. This is not so convenient, however.

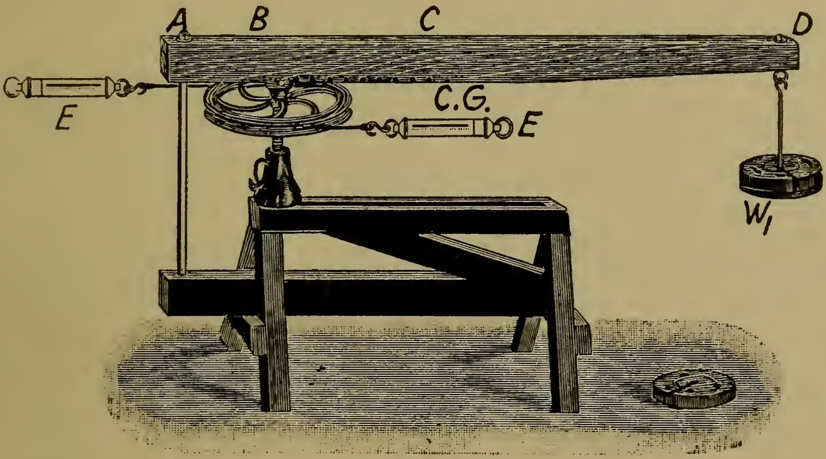

FIG. 125.—Laboratory apparatus for test of a jack screw.

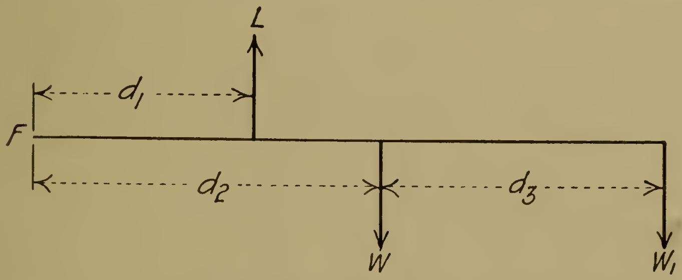

FIG. 126.—Force diagram for the jack screw.

To find the total load (L_2) raised by the effort (E), the following procedure is used. Referring to Figs. 125 and 126, it will be seen that A in the picture diagram becomes F in the force diagram and is considered the fulcrum of the lever. The "down" forces are the weight (W) of the lever concentrated at the center of gravity of the beam and the suspended weight (W_1)[1]. The "up" force is the pressure exerted against the beam at B and is labelled L on the force diagram.

Referring to Fig. 126 and applying a suitable law of levers, it will be seen that,

$$L \times d_1 = W \times d_2 + W_1 \times (d_2 + d_3)$$

L is determined in each case by the above formula. The total load (L_2) is equal to L plus the weight of the moving part of the jack.

The following experimental work on the jack screw was done in the mechanics laboratory of the Dickinson High School.

VELOCITY RATIO

(*a*) Circumference of hand wheel = 59 in.
(*b*) Lead of screw = .50 in.
(*c*) Computed velocity ratio 59/.50 = 118.

DATA

	Weight of beam (W) in lb.	Weight of jack in lb.	Suspended weight (W_1) in lb.	Effort (E) in lb.	d_1 in in.	d_2 in in.	d_3 in in.
1	23	36	50	18	12	44.5	49
2	23	36	100	31	12	44.5	49
3	23	36	150	44	12	44.5	49

EFFICIENCY

	Total load (L_2) in lb.	Input in ft.-lb.	Output in ft.-lb.	Efficiency in per cent.
1	511	2,124	511	24.0
2	900	3,658	900	24.6
3	1,290	5,192	1,290	24.8

---

[1] The "down" force at F is not considered, as its moment is zero.

Figure 127 is a graph constructed from the above figures. The low efficiency is accounted for by the excessive friction. As in the previous machines, *the effort is directly proportional to the load. The efficiency remains constant at around* 24 *per cent.* The part of the efficiency curve where no figures were taken is represented by a broken line.

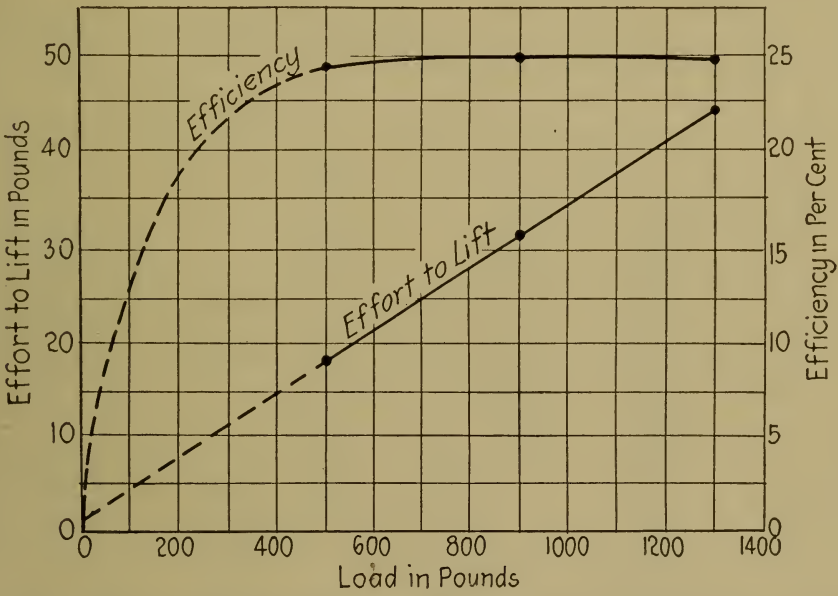

FIG. 127.—Graph showing relation of efficiency and lifting effort to load for the jack screw.

151. The Automobile Transmission.—Since a gasoline motor car delivers its maximum power at high speeds, it is absolutely essential that some device be provided for varying the velocity ratio between the crankshaft and the rear axles. This is effected by a special set of spur gears called the *transmission* or *change gears.*

Figure 128 shows a typical transmission. It consists of a *main shaft* and *countershaft,* each carrying *spur gears* and mounted on roller bearings.

The main shaft carries three gears: (1) the *main drive gear* which receives the power from the motor; (2) the *high* and *intermediate sliding gear;* and (3) the *low* and *reverse sliding gear.* The sliding gears are arranged to move along their shaft by means of a shifter fork, but the shaft and gears must rotate together. A shaft along which gears can slide and which rotates as a unit with the gears is often called a *spline shaft.*

The countershaft carries four gears, each solid with the shaft: (1) the *countershaft drive gear;* (2) the *countershaft second speed gear;* (3) the *countershaft first speed gear;* and (4) the *countershaft reverse gear.*

The *neutral* position of the gears in Fig. 128 allows the motor to run without transmitting any power to the propeller shaft. Since there is a "break" between the main drive gear and the high and intermediate sliding gear, the countershaft merely idles and the part of the main drive shaft connected to the final drive and carrying the sliding gears is cut off from the source of power.

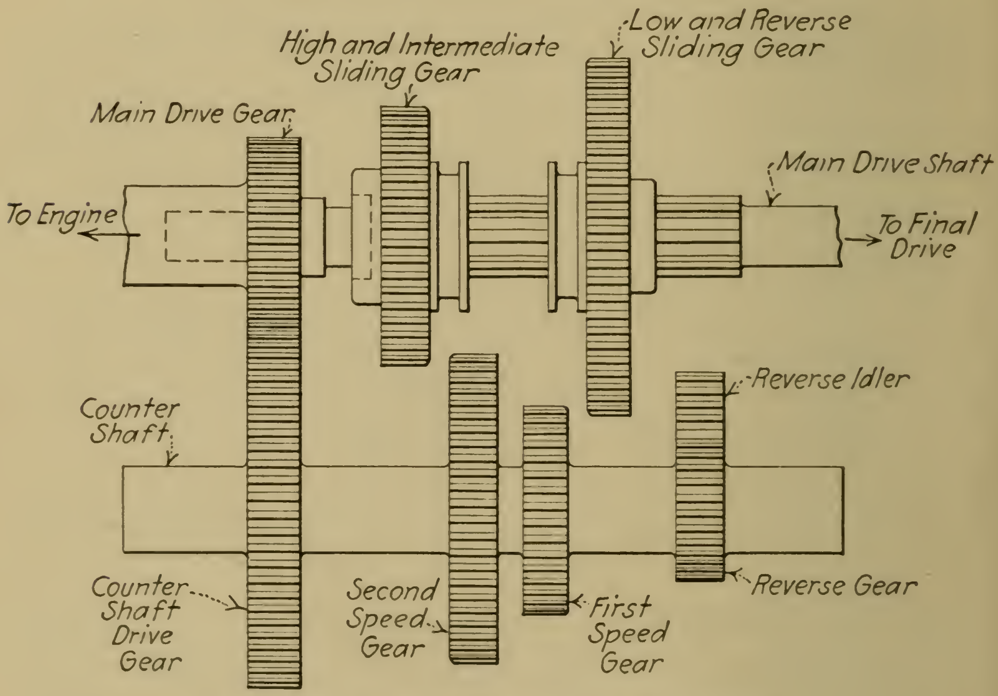

Fig. 128.—Typical automobile transmission.

First speed or "*low,*" used in starting and for heavy loads, provides the highest velocity ratio of the forward speeds. The low and reverse sliding gear is moved to the left by the shifter fork, engaging with the first speed gear on the countershaft. Thus the propeller shaft receives its motion from the motor by way of the countershaft.

Second speed or "*intermediate*" is obtained by moving the high and intermediate sliding gear to the right, so that it will engage with the second speed gear on the countershaft. The drive is through the countershaft and the velocity ratio is less than in the preceding case.

For *third speed* or "*high,*" the high and intermediate sliding gear is moved to the left, it internal teeth meshing with the external teeth at the right of the main drive gear. Thus, in third speed, the upper shaft rotates as a unit, while the countershaft idles. It will be seen that the motor crankshaft and the propeller shaft have the same number of r.p.m. The velocity ratio is less than in second speed.

For *reverse speed,* the low and reverse sliding gear is moved to the right, engaging with the *reverse idler.* The reverse idler is always in mesh with the reverse gear on the countershaft and runs idle except in reverse speed. The drive is through the countershaft.

It should be noted that the two sliding gears are *never* both in mesh at the same time. The shifter fork always removes the gear in mesh before putting the other gear in engagement.

Questions and Problems

1. State a general law of machines involving *effort*, *efficiency*, *load* and *velocity ratio.*

2. Discuss the construction and advantages of the chain blocks described in this chapter.

3. State how you would compute the velocity ratio of the above blocks.

4. Discuss the bicycle as a machine. How is the velocity ratio computed?

5. Describe a practical laboratory test for the jack screw. How is the velocity ratio calculated?

6. What general conclusions did you draw from a study of the graphs in this chapter? Why does an efficiency curve always start at the intersection of the "x" and "y" axis? Why does the load-effort graph always start above the intersection?

7. What is the purpose of the automobile transmission? Describe the transmission in detail, diagramming the position of the gears for each speed.

8. A differential type of chain hoist has 8 and 7 chain pockets respectively in the sheaves of the upper block. What is the velocity ratio? If the efficiency is 30 per cent., how much effort is needed to lift a load of 100 lb.?

9. The velocity ratio of a screw-geared chain block is 38. If the efficiency is 40 per cent., what load can be raised by an applied force of 10 lb?

10. In a laboratory test of a chain-drive bicycle (see Fig. 123), a force of 25 lb. applied to the driving pulley was necessary to overcome 5 lb. applied to the rear wheel. What is the velocity ratio if the efficiency at this load is 97 per cent.?

11. The velocity ratio of a jack screw arranged as in Fig. 125 is 200. If the efficiency is 25 per cent., what effort is necessary to raise a total load of 1,500 lb.?

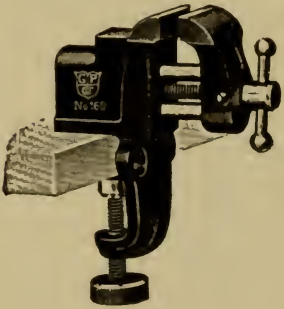

FIG. 129.

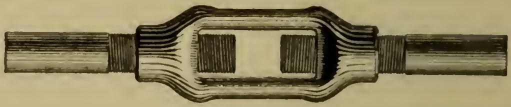

FIG. 130.

12. A wheel 12 in. in diameter makes 1,000 r.p.m. It is belted to a pulley 6 in. in diameter. The pulley is keyed to a second wheel 30 in. in diameter. Assuming a belt slippage of 10 per cent., determine the linear speed of a point on the circumference of the second wheel.

13. The screw of the bench vise in Fig. 129 has 9 threads to the inch. The effective lever arm of the hand lever is 5 in. Allowing a 65 per cent. loss due to friction, what clamping force is exerted by the jaws, if the applied effort is 15 lb.?

14. The turnbuckle in Fig. 130 has 12 threads to the inch. The threaded ends of the rods are 2 in. apart. How far apart will they be after 10 complete turns? Give two answers.

15. Devise a system of pulleys whereby one man pulling not over 75 lb. can lift a weight of 300 lb. Assume an efficiency of 75 per cent. Label the diagram carefully and prove its correctness.

16. The screw of a ⅝ in. bolt has 12 threads to the inch. The effective leverage of the wrench used in turning on the nut is 8 in. What is the clamping force exerted by the nut, if the effort applied to the wrench is 10 lb.? Assume a frictional loss of 70 per cent.

17. A machine delivering 8 hp. loses 500 ft.-lb. of work per second due to friction. What is the efficiency of the machine?

18. A simple hoisting winch consists of a pinion gear turned by a crank and engaging a larger gear. The larger gear turns a barrel around which the load chain winds. Crank lever = 20 in.; teeth in pinion = 24; teeth in larger gear = 72; diameter of barrel = 14 in.; load = 200 lb.; efficiency = 75 per cent. Find (*a*) the velocity ratio and (*b*) the effort to lift, if the force is applied perpendicular to the lever.

19. An automobile weighing 3,000 lb. is being towed up a 2 per cent. grade (2 ft. rise in a hundred ft.). Assuming friction to be 15 per cent. of the weight, what is the tension in the tow rope?

20. An electric motor, with a driving pulley 6 in. in diameter, makes 1,500 r.p.m. This pulley is belted to another pulley 8 in. in diameter. The latter pulley is keyed to a shaft terminating in bevel pinion with 15 teeth and engaging a bevel gear with 75 teeth. The bevel gear turns a third pulley 10 in. in diameter. How many r.p.m. does the 10 in. pulley make? Assume no belt slippage.

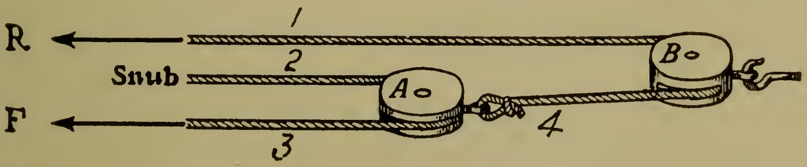

FIG. 131.

21. The "whip on whip" pulley arrangement shown in Fig. 131 is used for dragging guns out of ditches, etc. *B* is fastened to a convenient tree, let us say; *R* to the gun mount; and the snub to a stump. The effort is applied at *F*. Assuming an efficiency of 100 per cent. and that the ropes and blocks have no weight, find: (*a*) the relative distances travelled by *F*, *A* and *R*; (*b*) the tension in each strand, if 8 soldiers are exerting a force of 500 lb. at *F*; (*c*) the reaction at *B*.

22. In studying the transmission of a Studebaker six cylinder automobile (gears as in Fig. 128), two students submitted the following data: teeth on ring gear driving axles = 52; teeth on pinion driving ring gear = 14; teeth on main drive gear = 16; teeth on low and reverse sliding gear = 31; external teeth on high and intermediate sliding gear = 24; teeth on countershaft gears from left to right = 32, 24, 17 and 13 respectively. Compute the velocity ratio between the motor crankshaft and the rear axles for (*a*) first speed; (*b*) second speed; (*c*) third speed; (*d*) reverse speed.

CHAPTER XX

MECHANICAL TRANSMISSION OF POWER

152. Transmission of Power.—Various methods are employed in transmitting power from one point to another. The kind of transmission used will depend upon the nature of the work to be done. Mechanical transmission is effected by means of the following devices:

1. *Shafts*
2. *Couplings*
3. *Clutches*
4. *Cams*
5. *Links*
6. *Screw Threads*
7. *Chains and Sprockets*
8. *Friction Devices*
    - (*a*) Pulleys and Belts
    - (*b*) Pulleys and Ropes
    - (*c*) Friction wheels
9. *Toothed Gears*

153. Shafts.—A *shaft* is a rotating bar used in transmitting power. Shafts are usually of steel. Alloy steel, such as nickel or vanadium steel, is used for heavy work and when weight is to be kept down. Marine engine and automobile shafts are generally alloys. Hollow shafts have found much favor, as they are stronger in proportion to their weight than solid shafts.

A *line shaft* (Fig. 132) is made up of several lengths of shafting coupled together and forming a continuous run. It may or may not be a *main line shaft*.

The *main shaft* is a line of shafting attached directly to the prime mover (motor or engine). The crankshaft of an automobile is a part of the main drive shaft (Fig. 133).

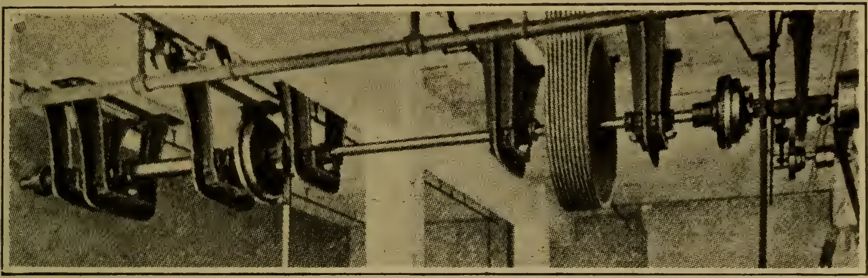

FIG. 132.—Line shaft used in a beet sugar factory.

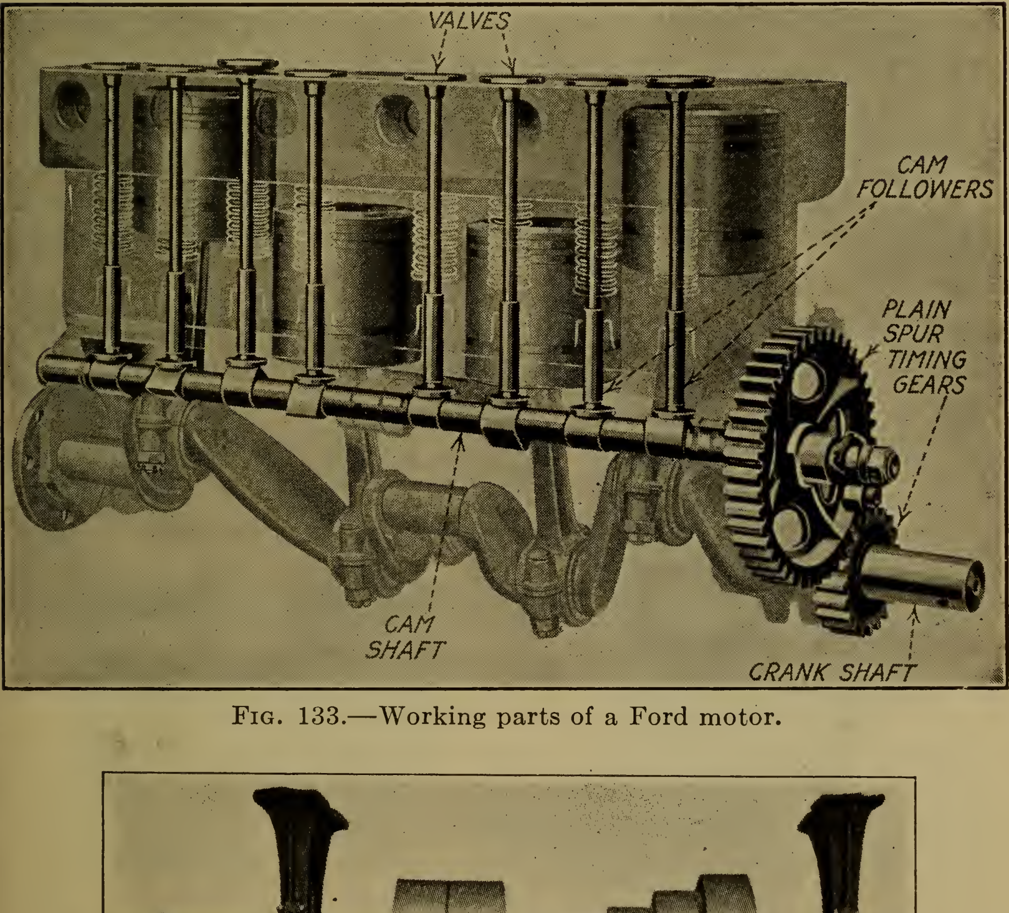

FIG. 133.—Working parts of a Ford motor.

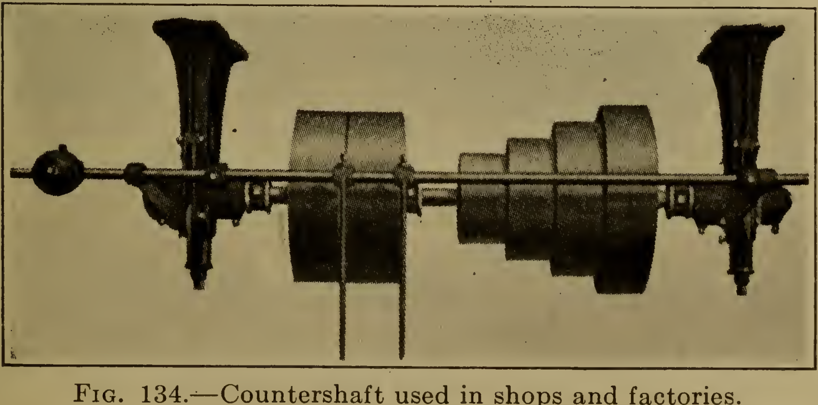

FIG. 134.—Countershaft used in shops and factories.

The *countershaft* is located between the main shaft and the driven machine. It is usually a short section and serves principally to effect changes of speed and direction. The cam shaft of an automobile (Fig. 133) is an example. The Dodge countershaft shown in Fig. 134 is widely used in factories and shops. Attention is also directed to the transmission countershaft in Fig. 128, by means of which various velocity ratios are made possible between the motor crankshaft and the rear wheels.

A *secondary shaft* is here used to include all shafts except main and countershafts. The spline shaft in Fig. 128, is a secondary shaft except in third speed. In third speed, it is a part of the main shaft.

A *flexible shaft* is used in transmitting power at a curved distance from the source. The dentist's drill and boring tools for mines, etc., are examples.

154. Couplings.—Line shafts exceeding 25 ft. in length are usually made up of separate sections joined together by *couplings*. Couplings are also used for short sections as in a motor-generator set.

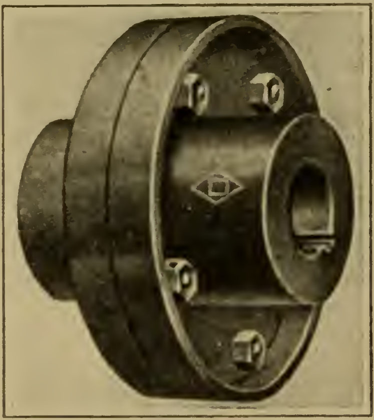

Fig. 135.—Flange fixed coupling.

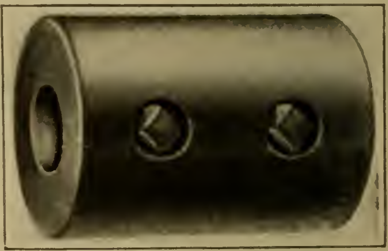

Fig. 136.—Solid-sleeve fixed coupling.

Fixed couplings are used when a shaft is subject to rotation only and is free from sudden and dangerous torques. The flange type of fixed coupling (Fig. 135) is generally used on large shafts. The solid sleeve fixed coupling (Fig. 136) is suitable for small shafts. Other types of fixed couplings are omitted through lack of space.

Flexible couplings are used for shafts liable to poor alignment or subject to sudden and dangerous torques. The flange flexible coupling (Fig. 137) is used for direct connections, such as gas engines, turbines, motors, generators, etc. The opposite parts are held together by flexible pins instead of rigid bolts. The pins are made of tempered steel leaves. Figure 138 represents an Auto-Lite starting motor used on Chevrolet motor cars. The driving pinion, engaging with teeth on the flywheel, is connected to the armature shaft by means of a coiled spring. Thus the spring absorbs much of the sudden initial torque.

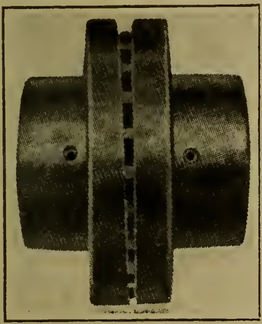

Fig. 137.—Flange flexible coupling.

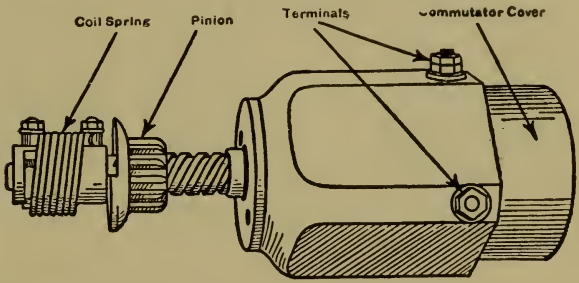

Fig. 138.—Flexible coupling of an automobile starting motor.

155. Universal Couplings.—*Universal couplings* are used for shafts subject to disalignment, as the propellor shafts of automobiles, etc.

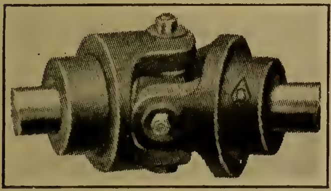

Fig. 139.—Single universal joint.

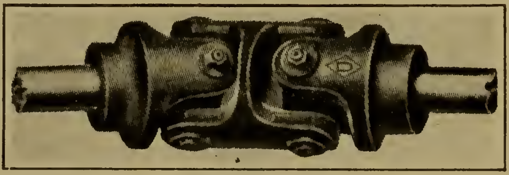

Fig. 140.—Double universal joint.

The universal couplings shown in Figs. 139 and 140 are constructed with steel bolts fitting into bronze bushings. The universal coupling is low in efficiency, but absolutely necessary for certain work.

156. Clutches.—Couplings which admit of ready disengagement are called *clutches.* Clutches are usually of the *positive* type or the *friction* type, although *magnetic* clutches have been used to some extent.

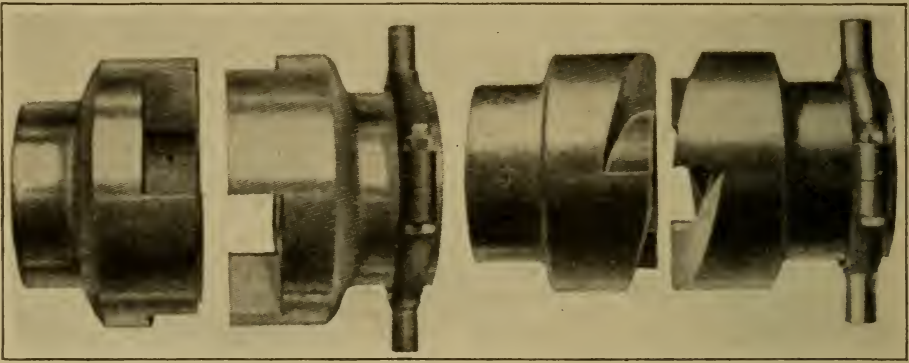

Fig. 141.—Common types of jaw clutches.

The *jaw* clutches shown above are of the positive type. It will be noted that the opposite parts interlock, eliminating any possibility of slippage.

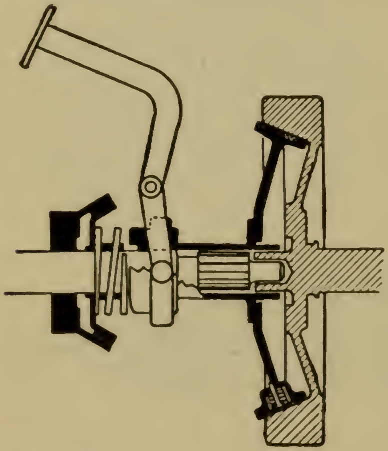

Fig. 142.—Cone clutch used on an automobile.

The *friction* clutch utilizes friction to hold the opposite parts together. Friction clutches are generally of the *cone* or the *disc* type, the contracting-band and expanding-band clutches having become nearly obsolete.

Figure 142 shows a cone clutch such as is used on automobiles. Friction is caused by the pressure of the clutch facing against the metallic balance wheel. The pressure is due to a very strong coil spring. The spring is adjustable, so that it may be compressed in case of slippage. By pushing in the clutch pedal, the transmission is cut off from the source of power. The cone clutch must be kept free from dirt and should be given an occasional application of Neat's foot oil or castor oil, if the facing is leather. Cone clutches must be re-faced eventually.

The cone clutch is rapidly being superseded by the multiple-disc clutch for pleasure cars. The multiple-disc clutch used on the Dodge car consists of seven discs held in engagement by a heavy coil spring. The driving discs (four in number) are carried by six studs projecting from the flywheel. The driven discs (three in number) are carried by three studs riveted to the clutch spider. The driving discs are faced on both sides with wire-woven asbestos fabric. The driven discs are unfaced steel. If the clutch pedal is pushed in, the spring is compressed and the driving discs can rotate independently of the driven discs. The source of power is thus cut off from the transmission. Modern practice favors the dry disc clutch as it gives a high coefficient of friction. Metal against metal gives a coefficient of .15 as a rule; this falls to about .07 if the surfaces become greasy. Metal against friction material will give a coefficient of .27 dry and .10 oiled. Thus it will be seen that metal against friction material tends to produce the greater friction. The disc clutch offers a large frictional area for a comparatively small clutch diameter. Furthermore, it does not "grab." Since wear is even, there is less danger of slippage and less necessity for renewal of facings.

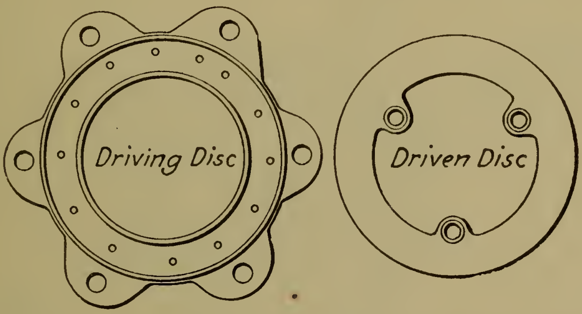

FIG. 143.—Discs from a Dodge multiple-disc clutch.

157. Cams.—The *cam* is an inclined plane in principle. The shape of a cam will depend upon its use. It is used to operate the valves of an internal combustion engine and to time the spark; to operate punch presses, shears, etc. Cams require good lubrication, as they work with a great deal of friction. They are necessary in certain cases, but should be avoided whenever possible. The cam mechanism for lifting the valves of a Ford motor is shown in Fig. 133. The six-sided cam in Fig. 144 is used on a Chalmers six cylinder motor for timing the ignition. Other cars use a similar arrangement. The point of the cam strikes the contact point lever, interrupts the flow of current in the primary circuit by separating the contact points, inducing a "jump" spark in the secondary circuit (and hence in the spark plug) at the proper instant.

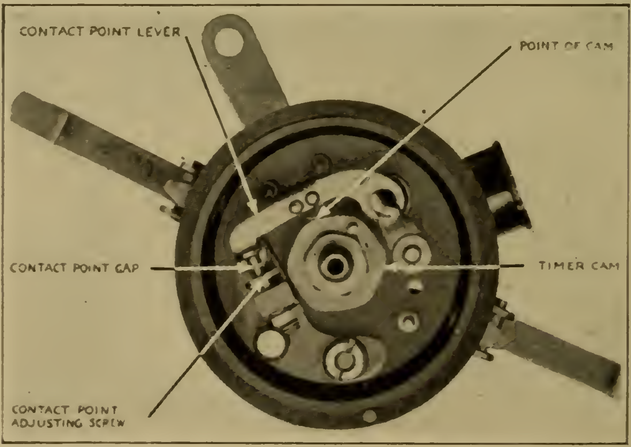

FIG. 144.—Automobile spark timer operated by a cam.

158. Links.—Power is often transmitted by means of *link work*, that is, by means of levers, cranks, rods, etc. Links may be used for all kinds of loads. The following are common examples of link action: the foot-treadle of a lathe; the connecting rod of a steam engine; the valve rod of a Corliss engine, etc. Link work should be used wherever possible, since it possesses the least friction of any kind of transmission.

159. Screw Threads.—The projections left in cutting helical grooves about a cylinder are called *threads*. External projections form *male* threads; internal projections form *female* threads. Thus a bolt is said to have male threads and a nut to have female threads. A screw is *single, double* or *triple* threaded according to the number of parallel threads which it has. The *lead* of a screw is the linear distance that the male or female part advances during one complete turn. The lead is often called *pitch* in connection with single threaded screws and is equal to the distance between the centers of two adjacent threads.

Screw threads are used for two purposes: *binding or fastening of parts* and *transmission of power*. Transmission screws are generally *square thread* or *acme thread,* as such threads operate with less friction than other kinds. The *square thread* screw is used on the jack screw, hand presses, etc. The *acme* thread is similar in construction, but the sides slope slightly. The acme screw is stronger and is used, for example, on the lead screw of a lathe. It is especially desirable for work in which the screw engages with a split nut. The split nut allows the connection to be broken at will. Screws of the "*V*" type are used for binding, as they operate with a large amount of friction.

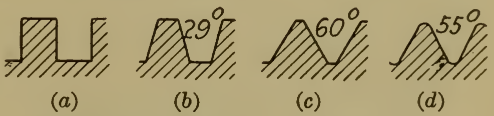

FIG. 145.—Types of screw threads: Square thread (*a*); Acme thread (*b*); American or Sellars thread (*c*); English or Whitworth thread (*d*).

160. Chains and Sprockets.—*Chains* are desirable for transmitting power short distances when slippage is to be avoided. They are extensively used for bicycles; automobile trucks, electrically driven machine tools, etc. Velocity ratios of 1–8 and linear speeds up to 4,000 ft. per minute are possible. The sprockets, as a rule, should not have under 16 teeth and the distance between the sprocket centers should not be less than 1½ times the diameter of the larger sprocket or more than 12 ft. As all chains stretch, provision must be made for shortening the chain or moving the sprockets farther apart. The pressure on the rivets or pins of a chain should never exceed 700 lb. per sq. in. Practical tests of a chain driven bicycle have shown an efficiency of 98 per cent. *Block,* *roller* and *Renold* (*silent*) chains are the ones most commonly used.

The Whitney *block chain* is shown in Fig. 146 and the patent *connecting link* for the same is shown in Fig. 147.

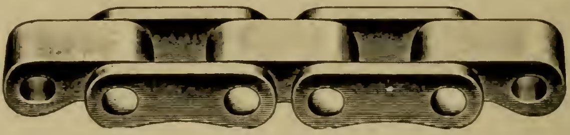

Fig. 146.—Block chain.

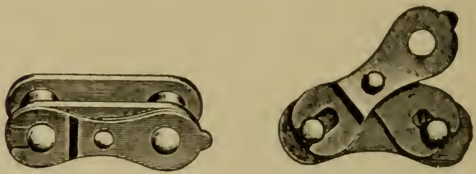

Fig. 147.—Patent connecting link.

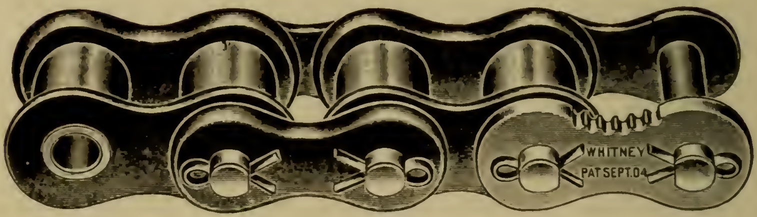

Fig. 148.—Roller chain (detachable type).

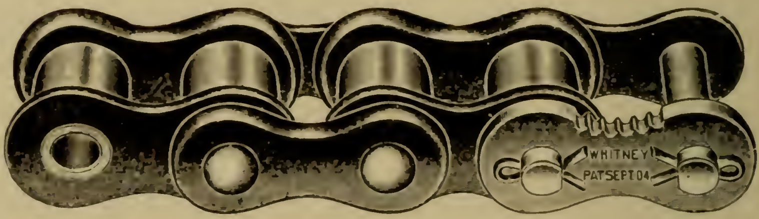

Fig. 149.—Roller chain (riveted type).

Block chains should not exceed 800 ft. per minute in linear speed.

The Whitney *roller chain* (*detachable type*) is shown in Fig. 148. The *riveted type* is shown in Fig. 149. It should be noted that the detachable type provides for easy removal or separation of links. Attention is also directed to the bushings surrounding the rivets or pins. This type of a chain will operate successfully up to a linear speed of 1,000 ft. per minute.

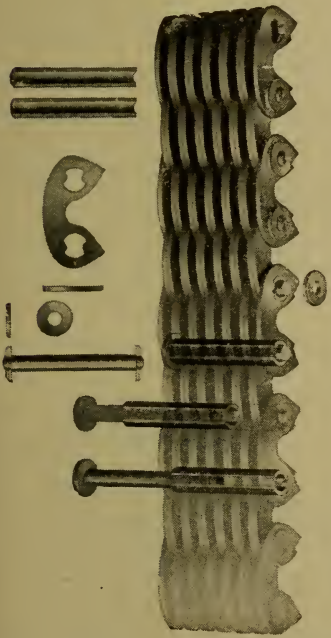

Fig. 150.—Link-Belt silent chain.

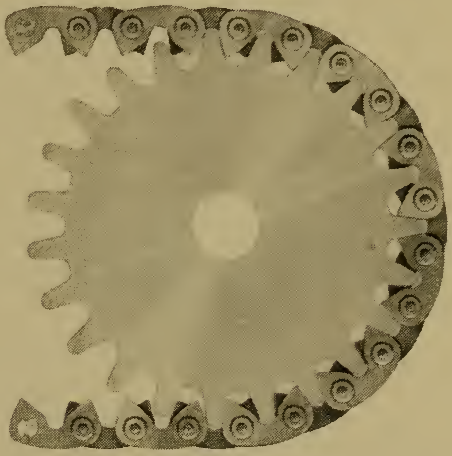

Fig. 151.—Link-Belt silent chain showing perfect fit to sprocket.

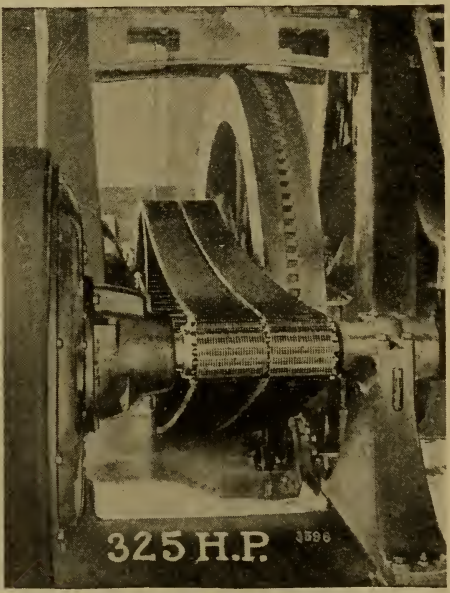

Fig. 152.—Double Link-Belt silent chain transmitting 325 hp.

The *silent chain* (Fig. 150) is manufactured by the Link-Belt Co., and is suitable for light or heavy duty. It is made of the best quality steel and consists of a series of leaves or plates held together by case-hardened bushings and case-hardened steel pins. Linear speeds of 1,500 ft. per minute are easily possible with this chain. Figure 151 shows how perfectly the chain fits on its sprocket, and Fig. 152 shows a silent chain in actual operation.

161. Pulleys and Belts.—*Belts* are extensively used for transmitting power up to 60 ft., beyond which rope transmis-

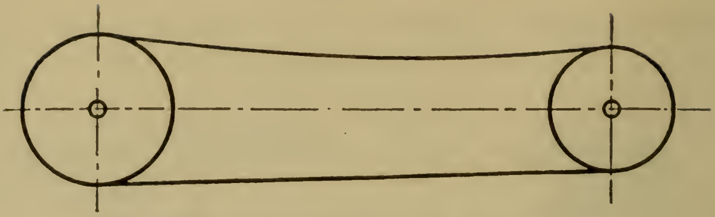

Fig. 153.—Open drive belt (top slack).

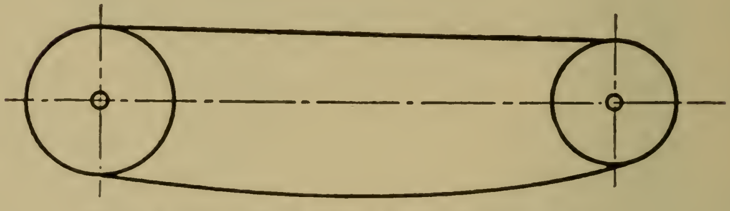

Fig. 154.—Open drive belt (bottom slack).

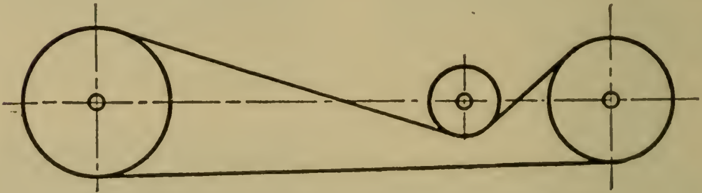

Fig. 155.—Open drive belt with fixed idler.

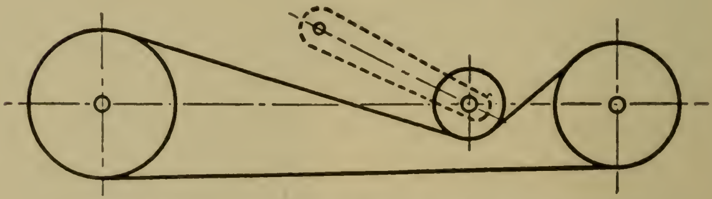

Fig. 156.—Open drive belt with swing idler.

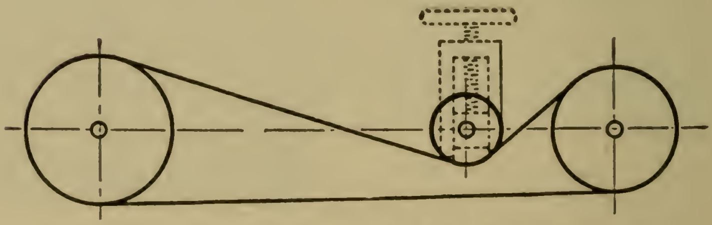

Fig. 157.—Open drive belt with adjustable idler.

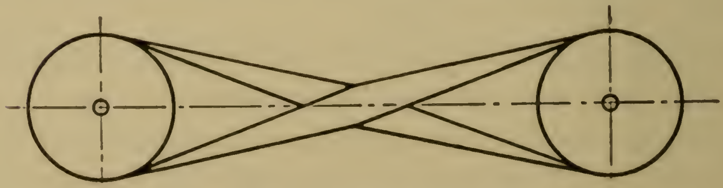

Fig. 158.—Crossed drive belt.

sion is cheaper. They are suitable for low, medium or heavy duty work. Leather belts are best, although cotton, hemp or rubber is used in damp places. The strongest and most durable belts are made of oak-tanned ox hide. Belt tension should not exceed 350 lb. per sq. in. of cross section. Electrical transmission has replaced the belt in the shop to a certain extent; yet the belt will always retain its field of usefulness.

All belts tend to slip or creep, resulting in wear and loss of power. By using *top slack* (Fig. 153) a greater area of contact is effected between pulley and belt and slippage is reduced.

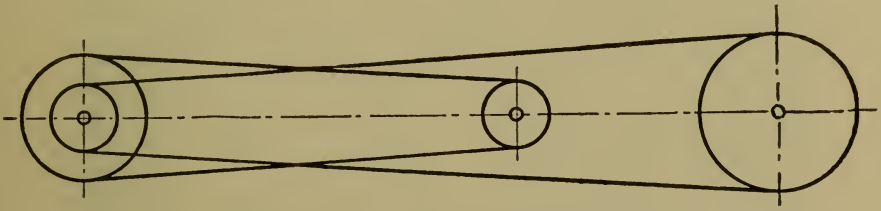

Fig. 159.—Compound drive belt.

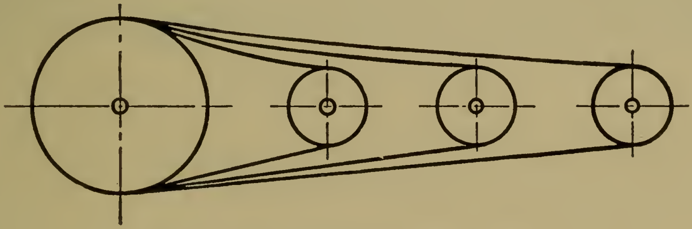

Fig. 160.—Tandem drive belt.

Figure 154 illustrates *bottom slack*. If pulleys are not lined up exactly, *guides* are necessary to keep the belt from coming off.

Short belts generally carry a *fixed, swing* or *adjustable idler* to minimize creep. It will be seen from Figs. 155, 156 and 157 that this arrangement provides greater frictional area between the pulleys and belt.

When the driven pulley must rotate opposite in direction to the driving pulley, *crossed drive* (Fig. 158) is used.

Figures 159 and 160 show the *compound* and the *tandem drive belt*. For further systems of belting the student is referred to a more advanced book.

Below is a photograph of a 30 in. double Ladew "Flintstone" belt 176 ft. long. This belt, according to the manufacturers, had just replaced another Ladew belt in continuous use for 18 years and crippled through accident, not wear.

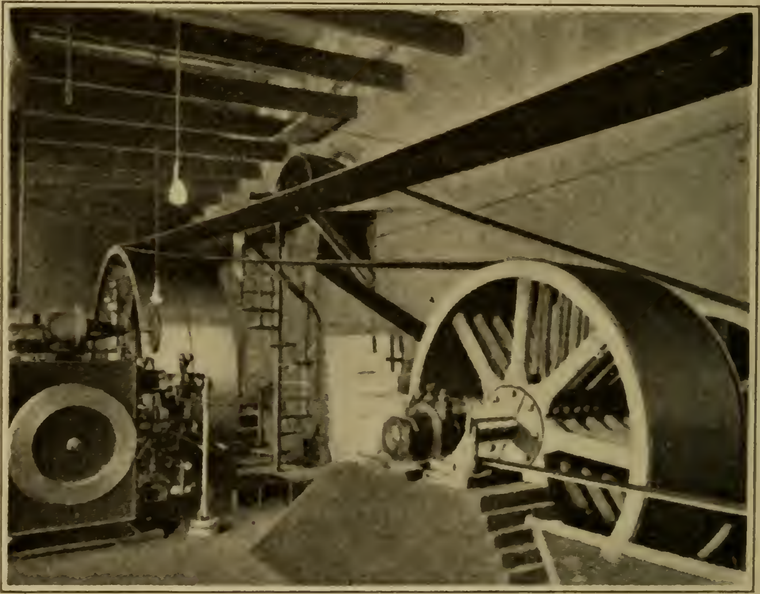

Fig. 161.—Ladew 30-in. belt (tandem drive) carrying 1,000 hp.

Referring to Fig. 162, *A* is a driving pulley and *B* a driven pulley, direction of rotation being shown by arrows. It is evident that the actual driving tension is largely T_2. T_1 is also in tension and tends to retard the clockwise rotation of *B*. Hence the total effective driving tension will be $T_2 - T_1$. In case there is no slippage, the horsepower transmitted is as follows:

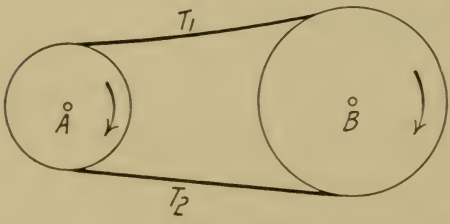

Fig. 162.

$$Hp. = \frac{\textit{difference in tension in lb.} \times \textit{velocity of belt in ft. per min.}}{33{,}000}$$

It is generally assumed that a single belt 1 inch wide and running 1,000 ft. per minute will transmit 1 horsepower. The rule is not exact, however. The following table, prepared by the Ladew Belting Co., will be found conservative.

HORSEPOWER TRANSMITTED BY SINGLE BELTS AT VARIOUS SPEEDS

Belt speed ft. per min.	750	1200	1800	2400	3000	3600	4200	4800	5400	6000
Width, inches	Horsepower									
1	1	2	3	4	5	6	7	8	9	10
2	2	4	6	7	9	11	13	15	16	18
3	3	5	8	11	14	16	19	22	25	27
4	4	7	11	15	18	22	25	29	33	36
5	5	9	14	18	23	27	32	36	41	45
6	6	11	16	22	27	33	38	44	49	55
8	7	15	22	29	36	44	51	58	65	73
9	8	16	25	33	41	49	57	65	74	82
10	9	18	27	36	45	55	64	73	82	91
12	11	22	33	44	55	65	76	87	98	109
14	13	25	38	51	64	76	89	102	115	127
16	15	29	44	58	73	87	102	116	131	145

162. Pulleys and Ropes.—*Rope transmission* is used extensively in medium and heavy duty work, for both main and individual drive, when the distance between shafts is relatively great. It is cheap to install and maintain, noiseless and very flexible in application.

Textile ropes are generally made of cotton, hemp or manila hemp. Cotton is very pliable and is preferred for light work. Manila hemp is the strongest and more suitable for heavy work. Textile ropes are made of strands (usually four and never more than six) wound around a central core. A special dressing or lubricant is used to overcome internal friction and insure long life. Figure 163 shows a four strand Dodge

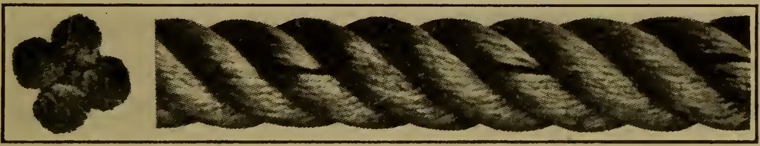

FIG. 163.—Manila transmission rope.

"Firmus" manila transmission rope. A four strand manila rope 1 inch in diameter will support a tension of nearly 9,000 lb. If the diameter is doubled, it will support a tension of over 32,000 lb.

Wire ropes are used to some extent, chiefly for hoisting purposes. The usual form consists of *six strands* with a hemp or wire core. Individual strands are composed of cast steel wires with tensile strengths as high as 250,000 lb. per sq. in. There are generally *seven* or *nineteen wires* to a strand. By making the wires less in diameter and increasing their number, greater pliability is obtained. Thus a nineteen-wire strand is more pliable than a seven-wire strand of the same cross-section. The wire rope in Fig. 164 has six strands, each strand being made up of nineteen wires.

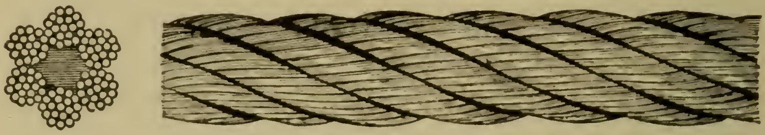

Fig. 164.—Wire transmission rope.

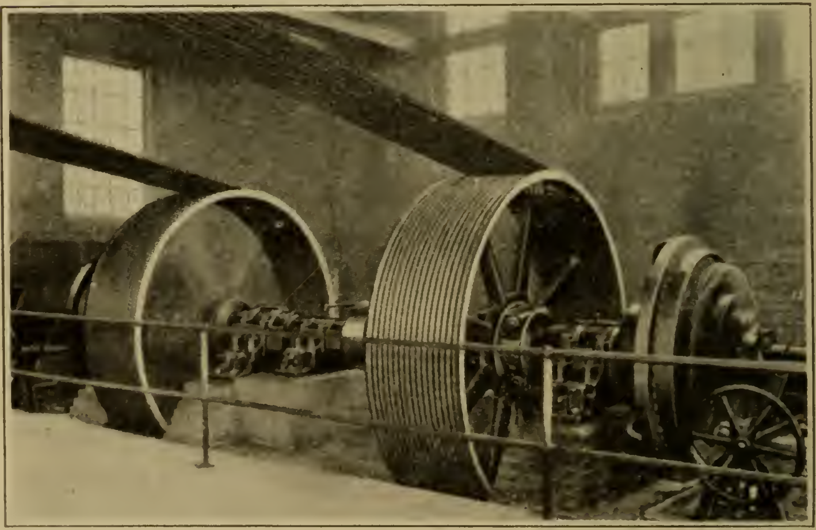

Fig. 165.—Rope transmission used in a hydro-electric plant.

Two systems of rope driving are in use: the English or *multiple* system and the American or *continuous* system. The

English system provides numerous separate ropes connecting the main drive pulley to the various driven shafts, or separate ropes connecting the main drive pulley to the main driven pulley, the latter operating the distributing shaft. The American system employs a continuous rope connecting the main drive pulley to the driven line shaft, to which shaft the separate units are attached. In case of a broken rope, the English system will not be out of commission entirely; a broken rope in the American system necessitates an immediate shut down. Figure 165 represents a rope transmission installed in a hydro-electric plant. The total power transmission is about 500 hp. Attention is called to the grooved pulleys. The grooves act as guides and also serve to increase the friction of the wheel and rope.

163. Friction Wheels.—*Friction wheels* are sometimes used for light and medium duty, in case various speed changes are desired. There are three types of friction wheels: the *spur*, the *bevel* and the *disc*. The friction surfaces may be of metal, wood, fiber, leather, etc. At best, friction wheels are unsatisfactory and have lost much of their popularity. It is nearly impossible to maintain an even pressure and there is great stress in the bearings. Figure 166 represents friction drive applied to an automobile. A steel plate is connected directly to the main drive and engages, at right angles, with

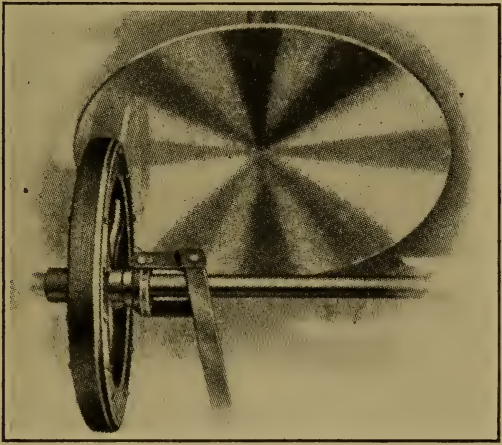

Fig. 166.—Friction drive formerly used on a Metz automobile.

a fiber covered wheel connected to the final drive. A gearset is thus avoided, changes of speed and direction being obtained by sliding the driven wheel along the spline shaft on which it is mounted. Friction transmission has attained very little prominence in the automobile world.

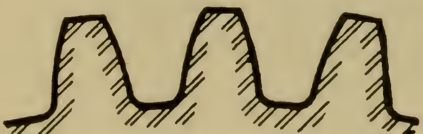

Fig. 167.—Involute gear teeth.

164. Toothed Gears.—*Toothed gears* form a very positive method of transmitting power from one shaft to another. Teeth from one gear engage similar teeth in another gear, slippage being avoided. For low speeds and rough work, gears may be *cast* from iron. For high speeds and where vibration is undesirable, gears are *cut* from steel. Alloy steel is generally used for the purpose. In order to cut down chatter, gears are sometimes made of fiber or rawhide. Such gears will not stand as much stress as steel gears and are used for light work, such as the timing gears of a gasoline motor. Most gears employ the *involute tooth* (Fig. 167), other shapes having become nearly obsolete. The elements of gear teeth may be either *straight lines* or *helical* (*curved*) *lines*.

165. Classification of Gears.—Gears are classified with reference to the elements of the teeth and the relative position of the shafts. Following is a general classification of gears in common use:

1. *Spur Gears.*—Connect parallel shafts; tooth elements straight.
2. *Bevel Gears.*—Connect shafts whose axes meet if prolonged; tooth elements straight.
3. *Worm Gears.*—Connect shafts that are not parallel and that do not meet if prolonged; consist of a wheel with curved tooth elements in engagement with a worm having continuous screw-like tooth elements.
4. *Helical Gears.*—Connect parallel shafts; tooth elements helical.
5. *Spiral Gears.*—Connect shafts that are not parallel and that do not meet if prolonged; tooth elements helical.

166. Spur Gears.—*Spur gears* have teeth whose elements are straight lines. They are used to connect parallel shafts that are close together. Spur gears are extensively used for automobile transmission, lathes, pumps, hoisting apparatus, etc.

Figure 168 shows the ordinary spur gear in engagement with its pinion (small gear). The annular or internal gear in Fig. 169 is used in the final drive of certain trucks. Attention is called to the fact that the tooth form of the internal gear is reverse in shape to that of the pinion gear.

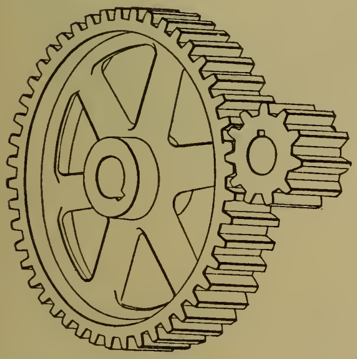

FIG. 168.—Spur gear and pinion.

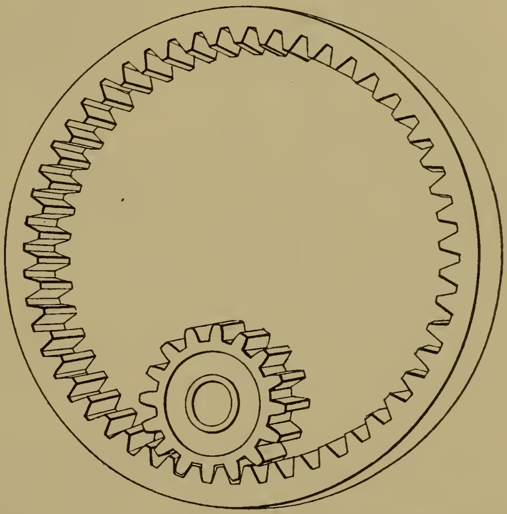

FIG. 169.—Annular or internal gear and pinion.

167. Bevel Gears.—*Bevel gears* have teeth whose elements are straight lines and connect shafts whose axes meet if sufficiently prolonged. The axes are usually at right angles, although such a condition is not necessary. A gear bevelled at an angle of 45° is called a *mitre* gear. If the teeth of a bevel gear are curved, it is called a *curved-tooth* or *helical bevel gear.*

The bevel gear in Fig. 170 has straight teeth. The helical bevel gear (Fig. 171) is commonly used in the final drive of most pleasure cars. The effect of the curved teeth is to obtain a smoother and quieter drive and to increase the number of teeth in contact at a given instant.

168. Worm Gears.—In *worm gears* the tooth elements are screw like; the shafts are not parallel and do not meet if prolonged. Worm gearing affords smooth running and high speed reductions and has been used with great success on motor trucks. The worm and worm gear shown in Fig. 172 is designed for rear axle drive, but can be used for other purposes if a speed reduction is desired. The particular gear shown here is phosphor-bronze and the worm is hardened

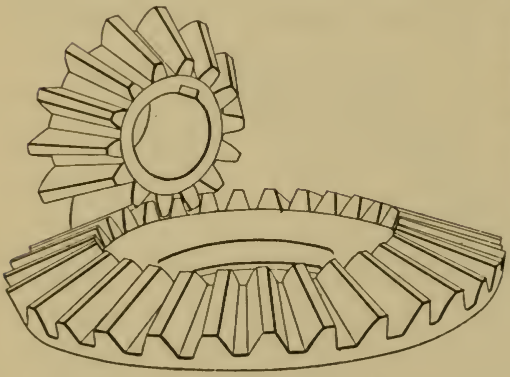

Fig. 170.—Bevel gear and pinion.

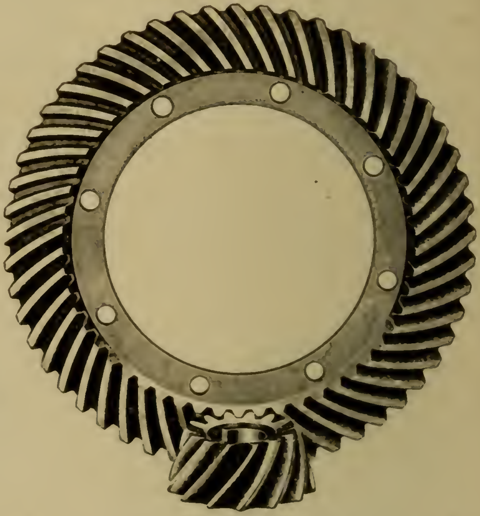

Fig. 171.—Helical bevel gear and pinion.

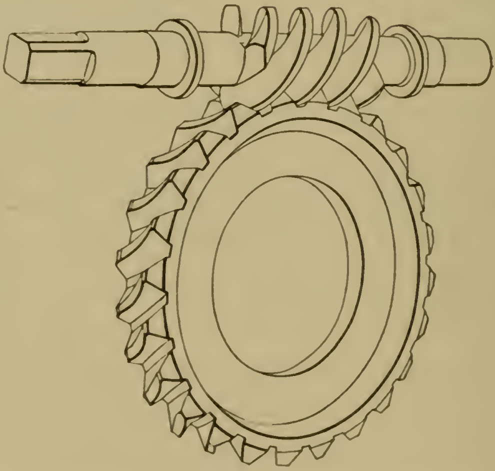

Fig. 172.—Worm and worm gear.

steel. The object of the wide tooth angle is to decrease friction. This makes for increased efficiency of transmission and longer life for the engaging parts.

169. Helical Gears.—The tooth elements of *helical gears* are curved or helical. Helical gears connect parallel shafts. They are stronger and quieter than spur gears of the same width. The timing gears of many automobiles are now of the helical type.

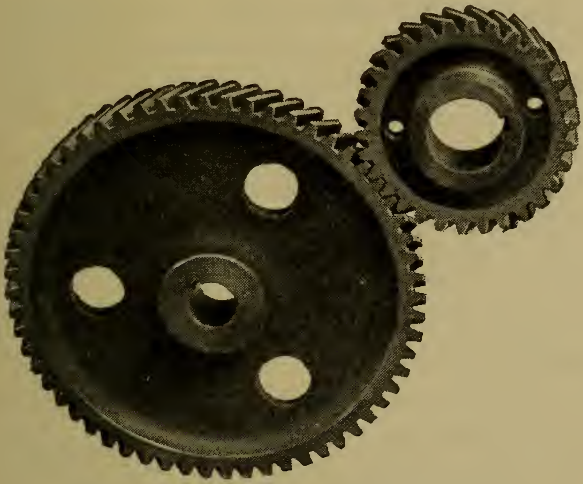

FIG. 173—Helical gear and pinion.

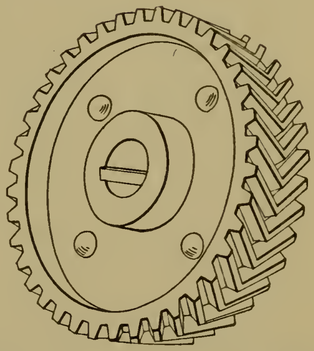

FIG. 174.—Double helical or herringbone gear.

Figure 173 shows a pair of plain helical gears, similar to those used for automobile valve timing. The double helical or herringbone gear (Fig. 174) is used for heavier duty.

170. Spiral Gears.—*Spiral gears* have curved tooth elements and connect shafts that are not parallel and that do not meet if prolonged. High speed reductions are possible and the connection of shafts in different planes is also brought about. Some authorities make no distinction between helical and spiral gears.

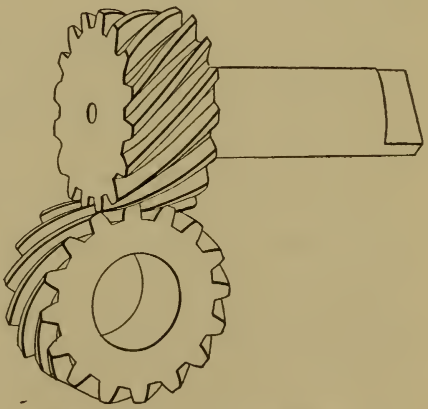

FIG. 175.—Spiral gears.

Questions and Problems

1. State nine general methods for the mechanical transmission of power.

2. What is the purpose of a shaft? Of what materials are shafts made?

3. What is meant by a line shaft? Main shaft? Countershaft? Flexible shaft? Secondary shaft? Give a practical example of each.

4. What is the purpose of a coupling? State the difference between a fixed and flexible coupling. When is a fixed coupling used? A flexible coupling?

5. What is a universal coupling? For what purpose is it used?

6. What is a clutch? For what kind of work is it used? Describe the jaw, cone and disc clutch. What advantage has the disc clutch over the cone clutch?

7. What is a cam? For what kind of work are cams used? Why are they avoided whenever possible?

8. What is a link? Give various examples of power transmitted by link work. Why are links used whenever possible?

9. What is meant by a thread? What is a male thread? Female thread? What is the difference between pitch and lead?

10. For what two general purposes are screw threads used? Describe four common types of threads.

11. For what kind of work is chain transmission desirable? Describe the roller, block and silent chain in detail.

12. When is belt transmission used? Why is "top slack" better than "bottom slack"? Show, using diagrams, various belt drives. Describe three kinds of idlers.

13. Given the difference in tension and the belt speed, how is the hp. transmitted by a belt determined?

14. Why is rope transmission much used? Describe the construction of the textile and wire rope. What is the difference between the American and English system of rope transmission?

15. Are friction wheels satisfactory in power transmission? Explain.

16. What is a gear? How are gears made? What is meant by the tooth element of a gear? Show by diagram an involute gear.

17. Into what five classes may gears be divided? Define each carefully and point out the kind of work to which it is adapted.

CHAPTER XXI

FLUIDS

SECTION I. INTRODUCTORY

171. The Three Forms of Matter.—Matter is divided into three general classes: *solids, liquids* and *gases.* The term *fluid* is used to include both liquids and gases. Many substances are capable of existing in any of the three forms. Water, for example, may readily be changed to ice or steam. Some substances are hard to classify, as they seem to occupy intermediate positions. In other words, there is an overlapping which makes the classification only approximate. Asphalt is ordinarily a solid, but on a very hot day will tend to flow and is then considered a liquid. The exact point at which matter changes from a solid to a liquid, liquid to a solid, etc., is often difficult to determine.

Solids have a definite shape and a definite volume and may be compressed to a certain extent. In solids the cohesive force between the molecules is relatively great, causing the molecules to maintain a fixed position with relation to each other. The latter statement in no way contradicts the statement, made earlier in the book, that molecules are always in vibration.

Liquids have a definite volume and an indefinite shape and are practically incompressible. A quart of water will maintain a constant volume, but will vary its shape to meet the shape of the containing vessel. The cohesive force between the molecules is insufficient to cause a rigid mass, enabling the molecules to move about with more or less freedom. The incompressibility of liquids is made use of in transmitting pressure through them from one point to another.

Gases have neither a definite shape nor a definite volume. There seems to be no cohesive force between the molecules; in fact, they behave as if they are in mutual repulsion. A gas like ammonia, if introduced into a room, soon expands and penetrates all parts of the room. All gases are readily compressible.

172. Density.—*Density* is the mass of a unit volume of a substance. In the f.p.s. system, density is measured in lb./cu. ft. In the c.g.s. system, density is measured in g./cm.^{3} For example, we speak of the density of water as 62.5 lb./cu. ft. or 1 g./cm.^{3} Density is determined by dividing the weight of a body by its volume.

$$\textit{Density} = \frac{\textit{mass}}{\textit{volume}}.$$

173. Specific Gravity.—*Specific gravity* is a number expressing how many times a substance is as heavy as an equal volume some other substance taken as a standard. For solids and liquids, water is the standard; for gases, hydrogen is usually the standard, although air and oxygen are sometimes used. The specific gravity of sulphuric acid is 1.8. This means that a cu. ft. of sulphuric acid weighs 1.8 times as much as a cubic foot of water.

$$\textit{Specific gravity} = \frac{\textit{weight of a substance}}{\begin{array}{c}\textit{weight of an equal volume of some substance}\\ \textit{taken as a standard}\end{array}}.$$

174. Pressure Defined.—The term "*pressure*" is used so commonly in physics that it is very important for the student to have a clear understanding of its meaning.

Pressure = force acting per unit area.

Pressure is generally given in lb. per sq. in. or in Kg. per sq. cm. For example, the manufacturers of the Goodyear 33 by 4 in. cord automobile tire recommend that the tire be kept inflated to a pressure of 70 lb. per sq. in. or 5 Kg. per sq. cm. The same pressure may be expressed more briefly as 70 lb. or 5 Kg., the corresponding units of area being understood.

Questions and Problems

1. Discuss the three forms of matter in detail.
2. Define density. Give examples.

3. Define specific gravity. Give examples. What substances are used as standards in specific gravity?

4. Show that density and specific gravity are numerically the same in the c.g.s. system.

5. Explain clearly what is meant by pressure.

6. What is the weight of a piece of cast gold (sp. gr. = 19.3) 10 cm. on a side?

7. Two hundred cm^3. of annealed copper weigh 1,778 g. What is its density? Specific gravity?

8. A sheet of silver .001 cm. thick and 1 m. square weighs 105 g. What is the density of silver?

9. A vessel is just filled with mercury (sp. gr. = 13.6). If the mercury weighs 20 lb., what is the volume of the vessel in cu. ft.?

10. A cast iron rod (sp. gr. = 7.1) is 1 in. in diameter and 6 ft. long. How much does it weigh?

11. A cu. ft. of cork weighs 15 lb. What is its specific gravity?

12. If 5 cu. ft. of sulphuric acid weigh 562.5 lb., what is the specific gravity of the acid?

13. How much does a liter of sulphuric acid weigh? Give answer in Kg.

SECTION II. MECHANICS OF LIQUIDS

175. Pressure in Liquids at Rest.—It is a matter of common experience that a pressure exists in all liquids. A wooden post thrust down into a body of water is forced back so that a portion of the post is out of water. Divers are unable to go very far down into the water due to the pressure to which their ears are subjected. Submarines rarely operate more than 200 ft. below the surface, on account of the tremendous crushing effect on the shell.

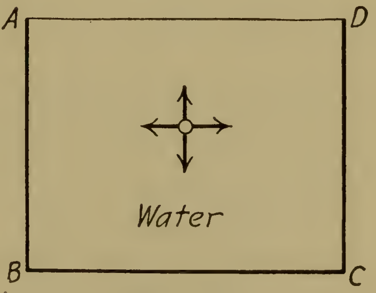

Fig. 176.

Pressure in liquids is due to the action of gravity on the various particles of which the liquid is composed. Assuming the liquid in Fig. 176 to be at rest, it is evident that any selected particle is in equilibrium; that is, the forces acting on the particle are balanced and their resultant is zero. If such were not the case, the particle would move and the liquid would not be at rest. *Hence, in a liquid at rest, pressure at any point must be equal in all directions.*

It is also evident that the pressure exerted by the liquid in Fig. 176 is normal or perpendicular to the surfaces of the container *ABCD*. Were this not true, a component of the pressure at any selected point would cause the liquid to move along the surface, contradicting our previous assumption that the liquid is at rest. *Liquid pressure, then, always acts at right angles to the retaining surface.*

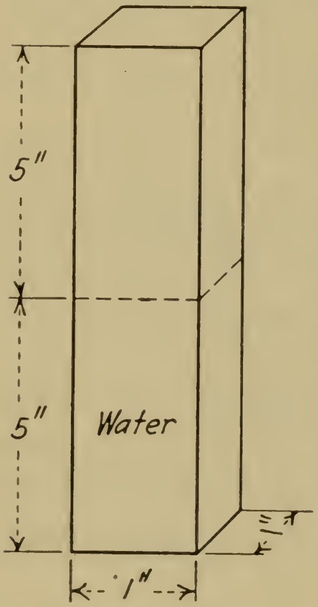

FIG. 177.

Liquid pressure on a horizontal surface is directly proportional to the depth of the surface beneath the surface of the liquid. Referring to Fig. 177, suppose we have a rectangular vessel 1 × 1 × 10 in. half filled with water. The pressure on the bottom will be equal to the weight of the water or 1 × 1 × 5 × .036[1] = .18 lb. per sq. in. If the vessel is entirely filled with water, the pressure on the bottom will be 1 × 1 × 10 × .036 = .36 lb. per sq. in. Hence by doubling the depth, we have doubled the pressure.

Suppose, further, that the vessel in Fig. 177 is filled with mercury (sp. gr. = 13.6). The pressure on the bottom will then be 1 × 1 × 10 × .036 × 13.6 = 4.89 lb. per sq. in., or 13.6 times as much as if the vessel were filled with water. *The pressure is directly proportional to the density of the liquid.*

From the above discussion, we may summarize as follows:

1. *At any selected point, the pressure exerted by a liquid is equal in all directions.*

2. *Liquid pressure always acts at right angles to the retaining surfaces.*

3. *The pressure in each layer of a liquid is proportional to the depth.*

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[1] 1 cu. in. water weighs .036 lb.

4. *With different liquids and the same depth, the pressure is directly proportional to the density of the liquid.*

Questions and Problems

1. Show that pressure exists in liquids.

2. State the laws of liquid pressure.

3. A vessel 20 in. high is filled with water. Find (*a*) the pressure on the bottom; (*b*) the pressure 10 in. down from the surface.

4. Find the pressure in Problem 3 if (*a*) the vessel is filled with mercury; (*b*) with sulphuric acid.

5. If the vessel in Problem 3 is filled partly with mercury and partly with sulphuric acid, find the pressure on the bottom.

6. A submarine lies so that a portion of the shell is 200 ft. below the surface of the ocean. If the sp. gr. of sea water is 1.03, what is the pressure on the shell?

7. A depth bomb is adjusted to explode at a pressure of 50 lb. At what depth will the explosion take place? Solve for salt water.

8. A reservoir is 70 ft. deep. Assuming a leakage under the retaining wall at this depth, what vertical pressure is exerted on the wall?

9. If the Titanic sank to an average depth of 3 miles, to what pressure is the ship subjected?

176. Transmission of Pressure by Liquids.—In the beginning of the chapter it was stated that liquids are practically incompressible. This property is made use of in transmitting pressure from one point to another through liquids, as in the hydraulic press, hydraulic jack, etc., in which a tremendous force may be exerted with only a small applied force.

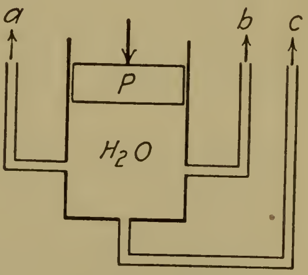

Fig. 178.

Suppose we have a vessel (Fig. 178) containing water, fitted with a plunger (*P*) and having orifices (*a*, *b* and *c*) of equal cross-section. If the plunger is pushed down, the pressure of the plunger will be transmitted to the liquid and will cause the water to issue from the orifices in streams of practically equal length. This shows that the pressure has been transmitted through the liquid equally in all directions.

177. Pascal's Law.—The following law, of great importance in hydraulics, was enunciated by Pascal:[1]

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[1] Blaise Pascal (1623–1662). French scientist, mathematician, philosopher and author.

Pressure exerted on any part of a confined liquid is transmitted equally in all directions, acts with equal force on equal surfaces and at right angles to the surfaces.

Pascal's Law Illustrated.—C and c (Fig. 179) are two communicating cylinders with cross-sections of 20 and 2 sq. in. respectively. P and p are tight-fitting pistons (considered weightless). The space between the pistons is filled with some liquid as oil. Suppose a force of 5 lb. is acting vertically down on p. There is, then, a force of 2.5 lb. per sq. in. being transmitted to the liquid by the plunger. Since the liquid is subject throughout to a pressure of 2.5 lb. per sq. in., a pressure of 2.5 lb. per sq. in. is transmitted to every sq. in. on the piston P. The total force tending to lift P is therefore 2.5 × 20 or 50 lb. In order to prevent P from moving upward, a weight of 50 lb. must be placed on P. In the above case, an applied force of 5 lb. is sufficient to balance a load of 50 lb. The resisting and applied forces are directly proportional to their respective cross-sections Algebraically:

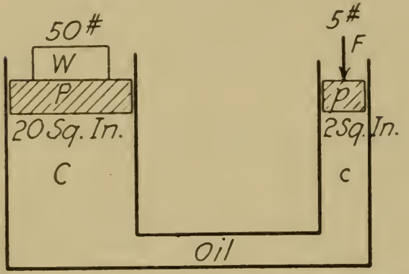

Fig. 179.—Apparatus for verifying Pascal's law.

$$W : F :: A : a$$

176. The Hydraulic Press.—Figure 180 is a simple diagram showing the essential parts of a hydraulic press. The press is used to compress cotton into bales and for similar work, whenever it is desired to secure a large force by the application of a small force. The gain in force is effected by making P large in comparison with p and by means of the hand lever operating the smaller piston.

The total crushing effect at R (friction neglected) is found as follows:

$$R = E \times \frac{area\ P}{area\ p} \times \frac{ac}{ab}.$$

Since the machine is considered frictionless, the output at R will equal the input at E. Hence:

E × downward distance E moves = R × upward distance P moves.

The student should note that, while a gain in force is secured, *there is no gain in energy.* This is strictly in accordance with the law of conservation of energy previously studied.

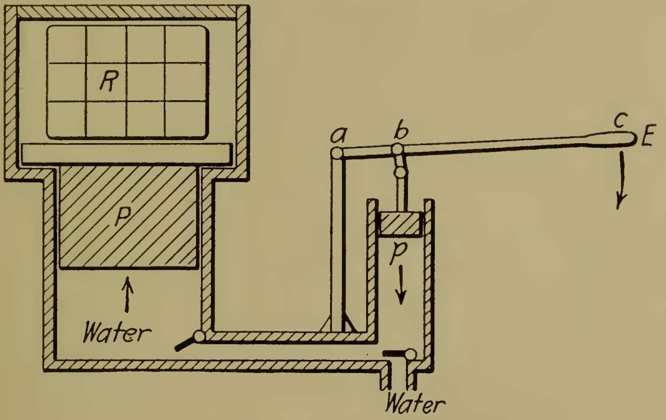

FIG. 180.—Hydraulic press.

177. Communicating Columns.—It is a common saying that "water seeks its own level." This is simply another way of stating that water contained in communicating vessels will come to rest at a common height. Referring to Fig. 181, it will be seen that column *A* contains more water than column *B*. Nevertheless, the level in each column is the same. This is explained by Pascal's Law. Since pressure is dependent

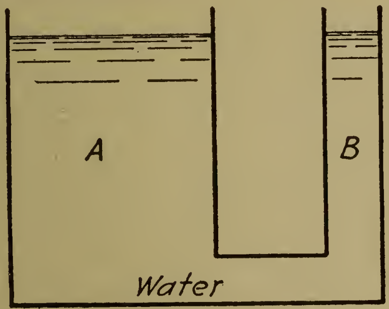

FIG. 181.—Communicating columns.

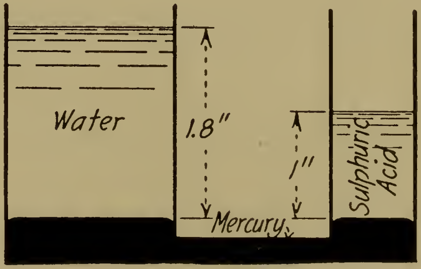

FIG. 182.—Heights of liquids are inversely proportional to their respective densities.

upon depth, it is clear that, in order for the pressure at the base of each column to be the same and keep the liquid in equilibrium, the liquid in the separate columns must have the same depth.

If liquids of different densities are used, the heights will be inversely proportional to the densities of the liquids. For instance, Fig. 182 represents a column of water and a column of sulphuric acid separated by mercury to keep them from mixing. The mercury is first put in and will come to rest with both surfaces at a common level. Since it is necessary that the level of the mercury shall not change, the pressure of the water against the mercury must be the same as the pressure of the acid against the mercury. As sulphuric acid is 1.8 times as dense as water, this condition can be brought about only by having the water column 1.8 times as high as the acid column. Stated algebraically:

$$H : h :: d : D,$$

in which H and h are the heights corresponding respectively to the densities D and d.

178. Difference Between Pressure and Weight.—Pressure exerted by a liquid on the base of a vessel depends in no way upon the shape of the vessel: only upon the depth and density of the liquid. Suppose (Fig. 183) a, b and c to be three vessels each with a base of 1 sq. in., 10 in. high and filled with water. The pressure at the base of a will be 1 × 10 × .036 or .36 lb. per sq. in. The weight of the water contained in a will be .36 lb. In this case the pressure exerted by the water and the weight of the water are the same. Similarly, we find that the pressure in b and c is also .36 lb. per sq. in. Inspection, however, shows us that the weight of the water in b is less than in a; also, that the weight of the water in c is greater than in a. This proves that *pressure and weight are different terms.*

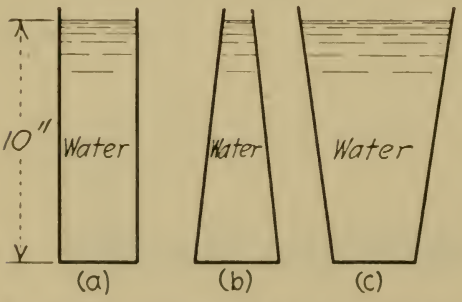

Fig. 183.—Diagrams to show difference between pressure and weight.

Questions and Problems

1. Why is a liquid better than a gas in transmitting pressure?

2. Give an experiment to show that liquids transmit pressure equally in all directions.

3. State and illustrate Pascal's Law.

4. Describe the principle of the hydraulic press.

5. Explain why "water seeks its own level."

6. State the law of heights for communicating columns of different densities.

7. Give an illustration to show that weight and pressure are not the same.

8. Two communicating vessels (*A* and *B*) contain water and are fitted with pistons. The piston areas are 10 and 1,000 sq. in. respectively. If a downward applied force of 50 lb. is used on the smaller piston, find (*a*) the pressure transmitted by each piston; (*b*) the lifting effect of the larger piston.

9. Repeat problem 8, if the pistons have diameters of 4 and 8 in. respectively.

10. The small piston of a hydraulic press, as shown in Fig. 180, is 2 in. in diameter and the larger piston is 12 in. in diameter. *ac* is 36 in. and *ab* is 6 in. Find the crushing effect at *R* if *E* is 40 lb.

11. Find *R* in problem 10, if a mechanical efficiency of 75 per cent. is assumed.

12. Find *E* in problem 10, if *R* is 1,000 lb. Assume an efficiency of 70 per cent.

13. In Fig. 182, if the water is 5 in. deep and the cylinders are 100 and 10 sq. in. respectively in cross-section, what weight of sulphuric acid must be used to keep the mercury level unchanged?

181. Total Pressure on the Various Plane Surfaces of a Vessel Containing a Liquid.—Pressure has been defined as the force acting per sq. unit of surface. It is frequently necessary to compute the total force acting against an area exceeding a sq. unit in size. This total force is called *total pressure* and must be distinguished carefully from *pressure.* Total pressure is simply the sum of the separate pressures.

(1) Horizontal Surfaces

We have seen that the liquid pressure on a horizontal surface is equal to the unit area × the height of the liquid × the density of the liquid. It follows, therefore, that:

The total liquid pressure acting upon a horizontal surface equals the area of the surface × the depth of the liquid × the density of the liquid.

(2) VERTICAL SURFACES

In dealing with vertical surfaces, we must take into account that the pressure against the surface is not constant, but increases with the depth. The total pressure will then be the area of the surface × the average pressure of the liquid. We may state the rule for total pressure as follows:

The total liquid pressure acting upon a vertical surface equals the area in the liquid × the vertical distance from the center of gravity of the surface to the top of the liquid × the density of the liquid.

(3) SURFACES NEITHER HORIZONTAL NOR VERTICAL

Since liquid pressure always acts at right angles to any surface, the rule stated in (2) is applicable to surfaces which are not vertical or horizontal.

The student should note that the law in (2) holds in (1) as well. Hence the rule given in (2) for vertical surfaces may be used for any plane surface in the solution of problems.

182. Center of Pressure.—Since pressure against a submerged surface always acts at right angles to the surface, we may conceive of the total pressure as being made up of countless parallel forces. The total pressure is the resultant of the separate forces.

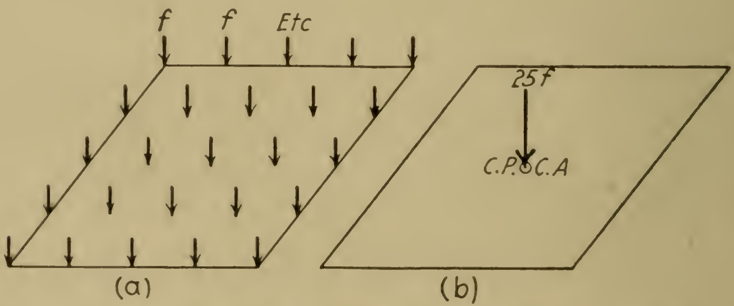

FIG. 184.—Center of pressure for a horizontal surface.

Figure 184(*a*) represents a horizontal surface acted upon by parallel forces. Since the forces are equal, we may assign a value of "*f*" to each. As there are 25 forces, the resultant is evidently 25*f*. If we replace the separate forces by a single force of 25*f* applied at the center of area of the surface as shown in Fig. 184(*b*), the effect will be the same as in Fig. 184(*a*). *The point at which the separate parallel liquid forces acting against a submerged surface may be replaced by a single, resultant force, is called the center of pressure for the surface.* For horizontal surfaces, the center of pressure is always at the center of gravity of the surface.

In case the submerged surface is vertical and rectangular, the center of pressure will be located *below* the center of gravity. This is due to the fact that the pressure increases with the depth as shown in Fig. 185. Referring to Fig. 185, we may represent the separate forces by *f*, 2*f*, 3*f* and 4*f*. The resultant force is 10*f*. It will be seen, by inspection, that the resultant force (10*f*) must be applied below the center of gravity to produce the same effect as the separate forces. In this case, the center of pressure is ⅔ of the vertical distance from the top of the surface to the base.

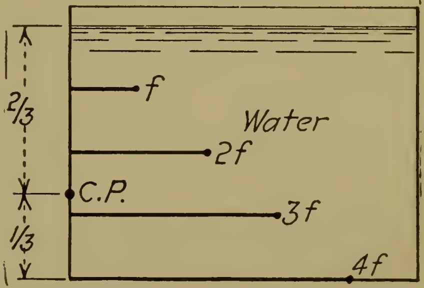

Fig. 185.—Center of pressure for a rectangular vertical surface.

For surfaces not horizontal, and submerged so that the top is in line with the level of the liquid, the center of pressure is located as follows:

1. *Rectangular Surfaces.*—Center of pressure is ⅔ the vertical distance from the top to the base.
2. *Triangular Surfaces with Base Horizontal and Vertex at Top.*—Center of pressure is ¾ the distance from the vertex to the mid-point of the base.
3. *Triangular Surfaces with Base at Top.*—Center of pressure is ½ the distance from the mid-point of the base to the vertex.

183. Dams and Retaining Walls.—Great care must be exercised in the construction of dams and retaining walls.

The most important feature of a dam or retaining wall is the foundation. Poorly constructed foundations allow water to leak in, impairing the base and at the same time exerting an upward pressure. This may result in a failure of the structure.

Assuming a proper foundation, a dam or retaining wall is liable to failure in three ways: (1) *sliding horizontally;* (2) *crushing of materials;* (3) *overturning.*

1. Stability against sliding is obtained by making the structure sufficiently heavy and allowing plenty of friction at the base.

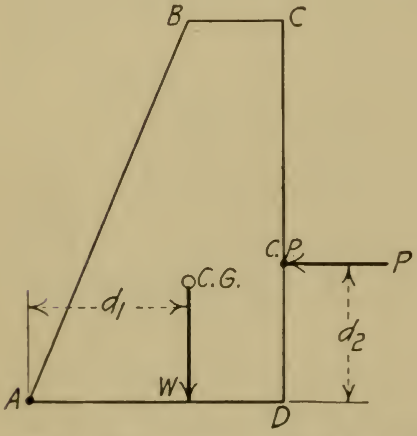

FIG. 186.—Dam *A-B-C-D* will not overturn around *A* if moment $W \times d_1$ exceeds moment $P \times d_2$.

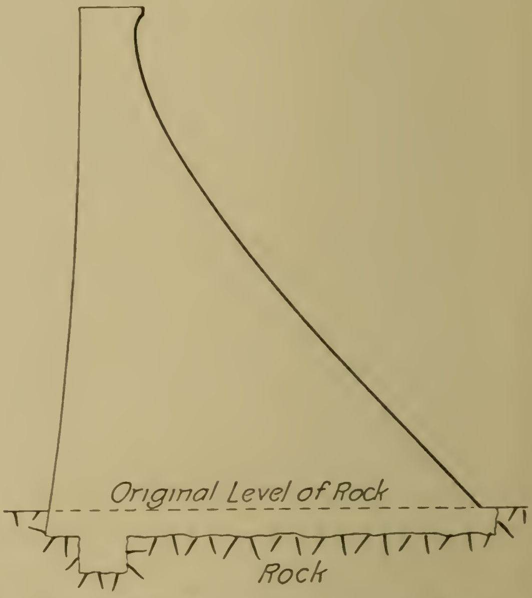

FIG. 187.—Transverse outline of the Ashokan dam.

2. Stability against crushing is obtained by keeping the compression, to which the material is subjected, less than its crushing strength.

3. Stability against rotation is obtained by making the structure heavy and thick at the base, causing the stabilizing moment to exceed the turning moment. For example, in Fig. 186, the dam *ABCD* if overturned would swing about *A* as a fulcrum. The moment tending to overturn the dam is

$P \times d_2$. P is the resultant liquid pressure applied at the center of pressure and d_2 is the moment arm or perpendicular distance to the fulcrum A. The stabilizing moment is $W \times d_1$. W is the weight of the dam concentrated at the center of gravity and d_1 is the corresponding moment arm. If $W \times d_1$ exceeds $P \times d_2$, there will be no rotation about A.

Figure 187 shows the outline of a transverse section of the Ashokan dam, a part of the water system for Greater New York. The masonry part is built of irregular rocks cemented with poured concrete and faced with concrete blocks. It is 1,000 ft. long and 220 ft. high. The width of base is 190.2 ft. and the width at the top is 26.3 ft.

Questions and Problems

1. Distinguish between pressure and total pressure.

2. State the rule for finding the total liquid pressure acting against a plane surface.

3. What is meant by center of pressure? Where is the center of pressure located in a submerged horizontal surface? Submerged vertical surface?

4. Why must the base of a dam or retaining wall be constructed carefully?

5. Assuming a proper foundation, mention three causes why a dam or retaining wall is liable to fail.

6. Explain the precautions taken to guard against failure as indicated by the answer to Problem 5.

7. Give a brief description of the Ashokan Dam.

8. A swimming tank is 50 ft. long, 35 ft. wide and 8 ft. deep. If the tank is filled with water, find (*a*) the weight of the water; (*b*) the total pressure on the bottom; (*c*) the total pressure on each side; (*d*) the total pressure on each end.

9. A dam is 100 ft. long and holds back a body of water 2 miles in length. If the water is 30 ft. deep, find the total pressure that the dam must withstand.

10. A gate in a dam is 1 m. wide and 2 m. high. The top of the gate is 4 m. below the water level. Find the total pressure against the gate in Kg.

11. A swimming tank 40 ft. long and 15 ft. wide is entirely filled with water. The water is 4 ft. deep at one end and slopes evenly to a depth of 6 ft. at the other end. Find (*a*) the total pressure on the bottom; (*b*) the total pressure on each end.

12. A submarine lies so that a certain horizontal section 2 m. square is 50 m. below the level of the water. Find the total pressure against the section in Kg. Density of sea water is 1.03.

13. A pressure gauge applied to a city main registers 75 lb. How high above the gauge is the water in the distributing reservoir?

14. A covered rectangular tank is 6 ft. long, 4 ft. wide and 4 ft. deep. A tube 6 × 4 in. and 24 in. high extends up from the cover. If the tank and tube are filled with water, find (*a*) the total weight of the water; (*b*) the total pressure on the bottom of the tank; (*c*) the total pressure on each end of the tank; (*d*) the total pressure on each side of the tank; (*e*) the total pressure on each surface of the tube.

184. Waterwheels.—Waterpower has been used for centuries. If available, it is both convenient and economical.

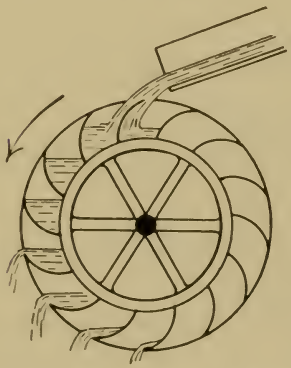

Fig. 188.—Overshot water wheel.

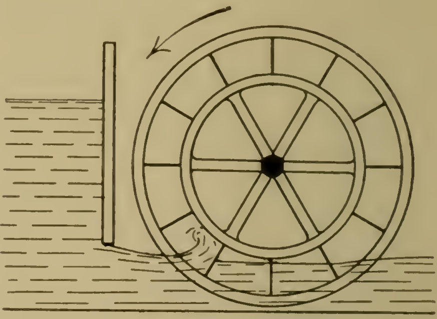

Fig. 189.—Undershot water wheel.

Many cities owe their existence and growth to natural waterfall. Water furnishes the motive power for mills, factories, electric plants, etc. Various types of waterwheels are in use. Modern practice favors the *Pelton* and the *turbine*, although the old-fashioned *overshot* and *undershot* wheels are still used to some extent.

The *overshot* wheel (Fig. 188) depends chiefly on the potential energy of the water flowing into the buckets; but some energy is derived from the impact of the water against the buckets. It has been used mostly in mountainous places where the fall is good, but the actual volume of water small. The efficiency of the overshot wheel is often as high as 90 per cent. The loss is due to the friction of the bearings, etc., as well as to the water which misses the buckets or which is spilled from them.

The *undershot* wheel (Fig. 189) is used in flat regions where there is a large volume of water with poor fall. It depends entirely upon the kinetic energy of the water. Not over 30 per cent. efficiency may be expected from a wheel of this type.

The *Pelton* wheel (Fig. 190) has met with much success. It is ordinarily used in water motors for household purposes or for other purposes where a small horsepower is desired. Pelton wheels have been built, however, capable of delivering several thousand hp. Water at high pressure is directed against the cup-shaped buckets and a large part of its kinetic energy is transferred to the wheel. The efficiency of the Pelton will often run over 80 per cent.

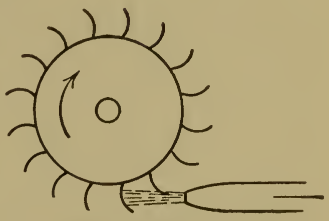
Fig. 190.—Pelton water wheel.

The prevailing type of water-wheel today is the *turbine*. The turbines at Niagara develop about 5,000 hp. each. Figure 191 shows a typical installation. Water enters the *penstock* and flows down into the *turbine case*. The turbine wheel rotates horizontally in an *inner case*. The *fixed*

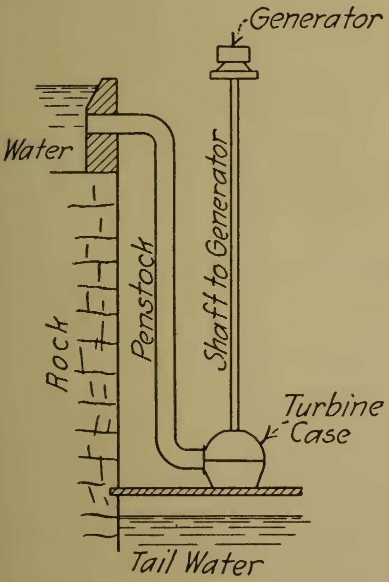

Fig. 191.—Water turbine.

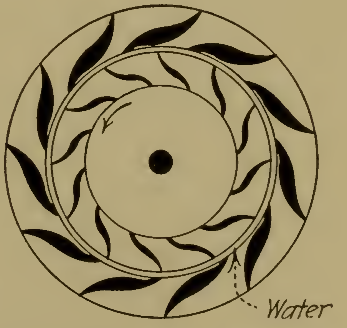

Fig. 192.—Diagram showing fixed and movable blades of a water turbine.

guides (Fig. 192) direct the water against the *movable* blades at the proper angle, rotating the wheel which is connected to the electric generator by a vertical shaft. After imparting a large part of its energy to the turbine, the water drops down into the *tail race.* The amount of water flowing through the case is controlled by means of a gate valve. The maximum efficiency will be about 90 per cent. The energy expended upon a turbine per second is equal to the product of the weight of the water flowing through it per second and the height of the water above the bottom of the pit.

Questions and Problems

1. Discuss waterpower as a source of energy.

2. Give the construction of an overshot waterwheel. Explain how it gets its energy. What is the maximum efficiency possible with a wheel of this type?

3. Repeat as above for an undershot waterwheel.

4. Describe the construction and operation of a Pelton waterwheel. For what kind of work is it generally used? What is the maximum efficiency to be expected?

5. Describe the construction and operation of a modern turbine power plant. Why is the turbine so efficient? How is the energy per second expended upon a turbine determined?

6. The hp. of a Niagara turbine is 5,000. The pit is 136 ft. deep. How much water passes through the turbine per minute, if the efficiency is 85 per cent.?

7. Repeat Problem 6, using efficiencies of (*a*) 80 per cent.; (*b*) 90 per cent.

185. Buoyant Force of Liquids.—It is common knowledge that bodies weigh less in water than in air. A heavy stone may be moved much more easily in water than in air. Floating bodies lose their entire weight when placed in a liquid. The following paragraph will explain the buoyant or lifting effect of liquids.

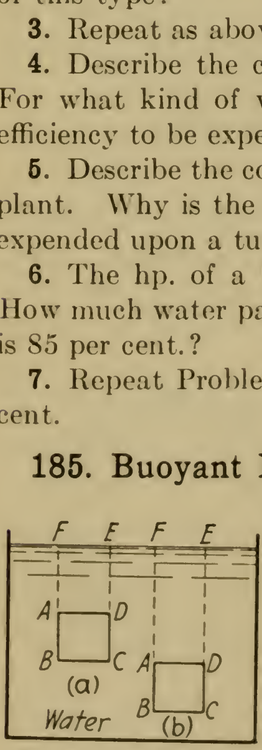

Fig. 193.—Diagram showing cause of buoyancy.

Referring to Fig. 193(*a*), we have a rectangular solid *ABCD* (side view shown) immersed in some liquid as water. The total pressure pushing the body downward is equal to the weight of a column of the liquid the size of the volume $FADE$. The total upward pressure at the base of the body is equal to the weight of a column of water the size of the volume $FBCE$. The buoyant force of the liquid is equal to the difference between the total upward and downward pressures or the weight of a column of liquid the size of $ABCD$. Since $FBCE = FADE + ABCD$, algebraically:

$$FADE + ABCD - FADE = ABCD$$

From the above, we see that the loss of weight of the body is equal to the weight of the liquid displaced. By similar reasoning, since liquids are practically the same density throughout, it may be proven in Fig. 193(*b*) that the buoyant force will remain the same if the body is farther down in the liquid. Hence we may consider buoyancy independent of depth.

The relation between the loss of weight of a body and the liquid displaced was discovered by Archimedes[1] and is called Archimedes' Principle.

Archimedes' Principle.—The loss of weight of a body immersed in a liquid is equal to the weight of the liquid displaced.

Since a floating body loses all of its weight when placed in a liquid, the weight of the liquid displaced must be equal to the original weight of the body.

Archimedes' principle furnishes a very convenient method of determining the specific gravity of solids. For bodies heavier than water, the procedure is very simple. The body is weighed in air and then in water. The *specific gravity is equal to the weight of the body in air divided by the loss of weight in water.* In case of floating bodies, it is necessary to attach a sinker to the body of sufficient size to submerge it. The following problems will illustrate each method.

---

[1] Archimedes (287–212 B.C.). Greatest mathematician of antiquity. Born in Syracuse, Sicily. First determined the value of π and the area of a circle. Discovered the laws of flotation and of the lever. Killed by a Roman soldier during the sack of Syracuse.

1. A piece of wrought iron weighs 10 lb. in air and 8.73 lb. in water. What is the specific gravity of the iron? It is evident that the loss of weight of the iron in water is equal to the weight of the water displaced. Therefore:

$$\text{Sp. gr. wrought iron} = 10/10 - 8.73 = 7.87$$

2. A block of paraffine weighs 2 lb. in air. It is attached to a sinker of sufficient size to submerge it. First the block and sinker are weighed with the sinker submerged and the paraffine in the air. This weight is 5 lb. Next the weight is taken with both submerged. This is found to be 2.76 lb. Hence the buoyant force of the water on the paraffine or the weight of a volume of water the size of the paraffine is 5 − 2.76 or 2.24 lb. Therefore:

$$\text{Sp. gr. paraffine} = 2/5 - 2.76 = .89$$

186. The Hydrometer.—A floating body displaces its own weight of a liquid. If the floating body is placed in liquids of different densities, the volumes displaced in the several cases will be inversely proportional to the respective densities. The *hydrometer*, an instrument for measuring the specific gravity of liquids, is constructed to work on this principle. The hydrometer shown in Fig. 194 consists of a glass tube with two bulbs. The stem and upper bulb contain air; the lower bulb is loaded with shot so that the apparatus will float upright. The instrument shown here is for liquids heavier than water. When placed in water, the graduation mark 1,000 is even with the water level. Since the specific gravity of water is 1, it is clear that we must read the 1,000 graduation mark as 1. When placed in sulphuric acid, the graduation mark corresponding to the acid level will be 1,800, showing that the specific gravity of sulphuric acid is 1.8. The lower graduation of the hydrometer here described is 2,000, giving a range of from 1 to 2. The hydrometer used for liquids lighter than water is usually graduated from 1,000 at the

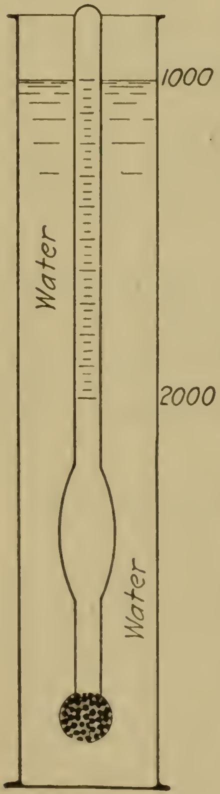

Fig. 194.—Constant-weight hydrometer.

bottom to 600 at the top. When working exclusively with certain liquids, special hydrometers are provided which are more sensitive. The hydrometer used to test milk is called a lactometer; for alcohol, an alcoholmeter, etc.

Questions and Problems

1. What is meant by the "buoyant force of liquids?"

2. State Archimedes' principle. Does it apply to floating bodies?

3. An aluminum block is 4 ft. long, 4 ft. wide and 3 ft. high. If the block is submerged in water, prove that the total upward pressure acting on the block minus the total downward pressure on the block is equal to the weight of the water displaced.

4. A piece of wood 4 in. square floats with ¾ of its volume submerged. Find (*a*) the weight of the wood; (*b*) the specific gravity of the wood.

5. A loaded auto truck is driven aboard a small ferry. The ferry is 30 ft. long and 15 ft. wide. If the ferry sinks 1½ in., what is the weight of the truck?

6. A body weighs 20 lb. in air and 10 lb. in water. Find its specific gravity.

7. A hollow ball of cast iron weighs 500 g. What must be its volume in cm^3. in order for it to remain suspended if submerged in water?

8. What must be the volume of the ball in problem 7, if kerosene (sp. gr. = .79) is used instead of water?

9. A sinker weighs 2,000 g. in air, 1,600 g. in water and 1,588 g. in salt water. Find (*a*) the specific gravity of the sinker; (*b*) the specific gravity of the salt water.

10. A piece of paraffine (sp. gr. = .89) is 1 ft. square. How far will it sink in a salt solution whose specific gravity is 1.03?

11. A wooden hydrometer $1 \times 1 \times 30$ cm. sinks 27 cm. in water and 25 cm. in a solution of copper sulphate. Find the specific gravity of the solution.

12. A body weighs 2 Kg. in air. It is attached to a sinker which alone weighs 3,000 g. in water. The sinker is just sufficient to submerge body. Find the specific gravity of the body.

13. A piece of wood weighs 2 Kg. in air. It is fastened to a sinker and the sinker and wood when suspended together under water weigh 3.5 kg. The sinker alone in water weighs 6 Kg. Find the specific gravity of the wood.

14. A uniform glass tube 5 ft. long has an outside cross-section of 4 sq. in. It is loaded with mercury at the closed end. The tube and mercury together weigh 15 lb. How many cu. in. of cork (sp. gr. = .25) must be fastened to the tube so that it will float upright with the top 1 ft. out of water? The cork must be entirely submerged.

SECTION III. MECHANICS OF GASES

187. Characteristics of Gases.—We have seen in Sect. I that gases have neither a definite shape nor a definite volume; that they readily admit of compression; and that they tend to expand indefinitely if unconfined. We may now state, in addition, that gases follow the laws of Pascal and Archimedes and that the pressure exerted by a gas at any point is equal in all directions. Gases expand when heated and contract when cooled. If a confined gas is heated, it will undergo an increase in pressure. If external pressure is applied to a confined gas (*e.g.*, the mixture of gasoline vapor and air in a gasoline motor cylinder), the volume of the gas will become less; if the pressure is removed, the gas will expand to its former volume. The above changes will be studied in detail later in the chapter.

188. The Atmosphere.—The earth is surrounded by a vast sea of atmosphere. Like liquids, the atmosphere has weight and exerts pressure. At sea level the air exerts a pressure of 14.7 lb./sq. in. or 1033.6 g./cm^2. For approximate work we may take the pressure as 15 lb./sq. in. or 1 Kg./cm^2. It is supposed, since the pressure decreases with altitude, that the extent of the atmosphere is limited. It is believed that no atmosphere exists at a distance of about 500 miles above the earth. Air is a mixture, containing about 20 per cent. by volume of oxygen and 75 per cent. by volume of nitrogen, as well as small quantities of carbon dioxide, water vapor, etc. At average sea level at a temperature of 0°C., the density of air is .0807 lb./cu. ft. or .001293 g./cm^3. Thus 12 cu. ft. of air weigh approximately a pound. A room may easily contain a ton of air. If the atmosphere had the same density at all altitudes as at sea level, it would extend upward about 5 miles. This height is called the height of the *homogeneous atmosphere*.

189. Proof that Air has Weight.—We may prove that air has weight by the following simple experiment. Figure 195 represents a two liter flask attached to the bell glass of an air pump as shown. First the flask and the air therein contained are weighed. The air is then exhausted and the container minus the air is weighed. The difference in the weights recorded is the weight of the two liters of air formerly contained in the flask. If the air pump is efficient, the true weight of the air will be found very closely and will be approximately 2.6 g./liter.

190. Proof that Air Exerts Pressure. It is a matter of every-day knowledge that the air exerts pressure. Automobile tires, foot balls, etc., depend upon air pressure. In constructing the Hudson Tubes under the North River, compressed air was used to prevent the water from entering the tubes while work was under way. The following demonstration proves most strikingly that air exerts pressure. A wood funnel is fitted tightly into a bladder glass (Fig. 196) and the bladder glass is attached in turn to the bell glass of an air pump. Mercury is poured into the funnel and the air is withdrawn from beneath it. The air pressure above forces the mercury through the minute pores of the wood into the catch basin below. This demonstration also proves that the wood is porous.

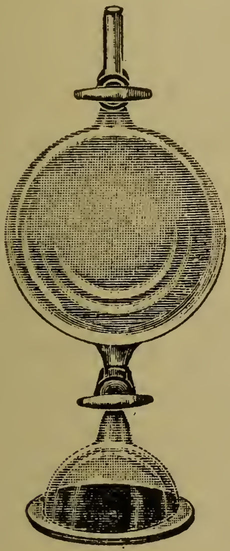

Fig. 195.—Apparatus to show that air has weight.

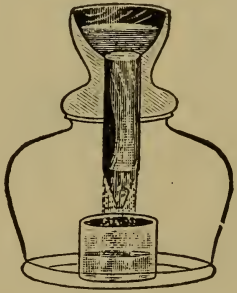

Fig. 196.—Apparatus to show that air exerts pressure.

191. Torricelli's Experiment.—The ancients were well aware of the fact that water would rise against gravity in exhausted tubes. This knowledge was utilized in lifting water from wells. The accepted explanation was that "nature abhors a vacuum." It was discovered early in the seventeenth century that water would not rise much over 32 ft. in an exhausted tube. Galileo's[1] explanation of this phenomenon was that "nature's horror of a vacuum ceased at 32 ft." It is probable, however, that Galileo suspected the true reason just before he died. After Galileo's death, Torricelli,[2] his pupil, reasoned since mercury is about 13 times as heavy as water, that mercury would rise only about 1/13 as high as water in an exhausted tube. In 1643 Torricelli performed the following experiment. He procured a glass tube about 4 ft. long and closed at one end. He then filled the tube with mercury, thereby expelling the air (Fig. 197). Placing his finger over the open end, he inverted the tube in a bath of mercury. The mercury then fell until its upper surface was about 30 in. above the level of the mercury in the dish, proving the original contention that mercury would rise 1/13 as high as water. Torricelli attributed the level of the mercury in the tube to the pressure of the air.

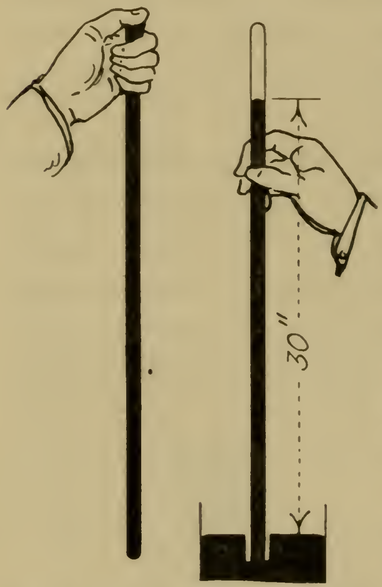

Fig. 197.—Torricelli's experiment.

192. Pascal's Experiment.—Pascal argued, if atmospheric pressure were the supporting force, that the column of mercury would fall somewhat at higher altitudes where the air is rarer.

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[1] Galileo Galilei (1564–1642). Born in Italy. Professor of mathematics at Pisa and Padua. Discovered the laws of falling bodies and the pendulum. Constructed the first thermometer. Made many valuable discoveries in astronomy. Considered the father of modern physics.

[2] Evangelista Torricelli (1608–1647). Italian physicist and mathematician. Successor of Galileo. Constructed the first microscope and improved the telescope.

Accordingly, he carried Torricelli's apparatus to the top of a tower in Paris and noted that there was a perceptible drop in the mercury column. A Torricellian apparatus may be used to determine altitude. At places near the sea level, the mercury will drop about 1 mm. for every 11 meters of ascent or 1/10 of an in. for every 90 ft. of ascent.

We may verify Pascal's experiment by the following demonstration. Referring to Fig. 198, we have an exhausted tube containing mercury to the approximate height of 30 in. or 760 mm., the open end dipping into a well of mercury. The apparatus is placed upon the plate of an air pump and covered with a high bell jar. The air is then exhausted within the jar and the mercury will fall until it is almost at the level of the mercury in the well. If the air is allowed to re-enter the bell glass, the mercury will rise to its former position. This shows conclusively that the rise of liquids in exhausted tubes is due to atmospheric pressure.

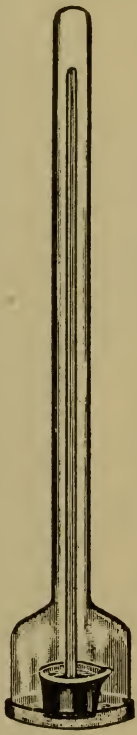

FIG. 198.—Apparatus to prove that the mercury column of a Torricellian tube is supported by atmospheric pressure.

193. The Mercury Barometer.—The ordinary mercury barometer is simply a Torricellian tube mounted as shown in Fig. 199(*a*). The tube terminates at the lower extremity in a generous sized reservoir with a flexible bottom (usually chamois). At the left, the scale is graduated in inches and tenths of inches; at the right, the corresponding range in millimeters. The protecting cap over the reservoir is constructed so as to afford a clear view of the mercury as well as the fixed white glass pointer (see Fig. 199(*b*)) which should always coincide with the convex surface of the mercury. Before reading the instrument, the thumbscrew must be so regulated that the pointer and the surface of the mercury will just meet. If the pressure[1] of the atmosphere increases, the mercury will ascend in the tube; if the pressure decreases, it will descend in the tube. In reading the barometer, great care must be exercised that the eye and the convex surface of the mercury in the tube are in a horizontal line. A rising barometer indicates fair weather; a falling barometer indicates that a storm is approaching. A sudden drop at sea indicates a storm of unusual severity. The barometer is not a sure storm prophet, yet it is very helpful in making weather predictions. While it may not storm at every low barometer, we know that the barometer is low whenever it does storm. The mercury barometer is used principally for stationary work and where the temperature is not sufficient to freeze the mercury. Mercury freezes at −39°C.

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[1] The rear of the mercury reservoir has a porous stopper.

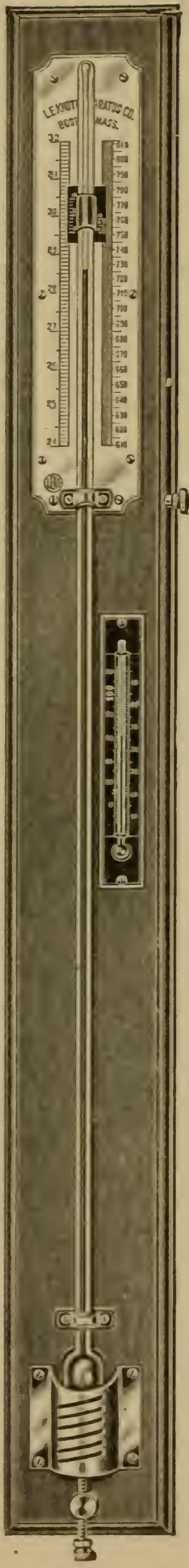

Fig. 199(*a*).—Mercury barometer.

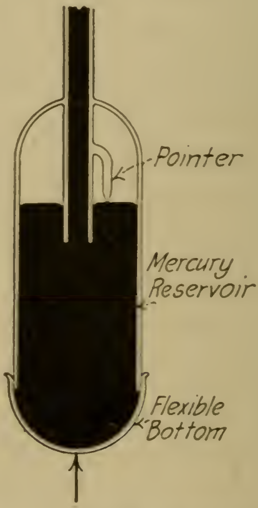

Fig. 199(*b*).—View of mercury reservoir in Fig. 199(*a*).

194. The Aneroid Barometer.—The aneroid barometer is shown in Fig. 200. It consists of a circular box of metal, the sides of which are thin, elastic and corrugated. The air is partially exhausted from the box and the box is then sealed. One side is securely fastened to the base and the other side operates against a system of levers, etc., which in turn move the pointer around the graduated dial. If the outside pressure increases, the front face of the box moves in, registering an increased pressure on the dial. If the outside pressure decreases, the face of the box moves outward and the pointer moves back due to the spring with which it is connected. Aneroid barometers are graduated by comparison with a standard mercury barometer. Aneroid barometers are very sensitive in operation but they frequently get out of order and need re-graduating. They are used for work in which it is necessary to move from place to place and also in the barograph which will be described in the next paragraph.

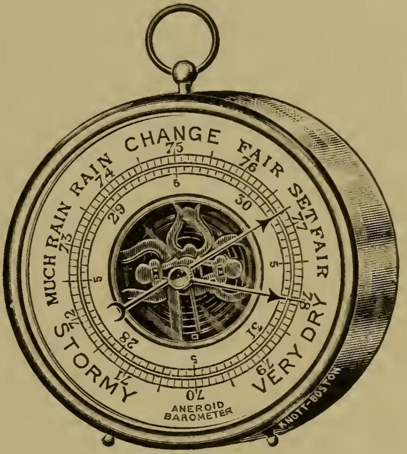

Fig. 200.—Aneroid barometer.

195. The Barograph.—The barograph, shown in Fig. 201, is an aneroid instrument designed to record automatically the varying pressures of the atmosphere. The drum, revolving once every seven days, carries a graduated chart. The variations of pressure cause movements of the lever, the free end of which carries a pen. Thus the pressure for an entire week is self-recorded on the chart. In this barometer the

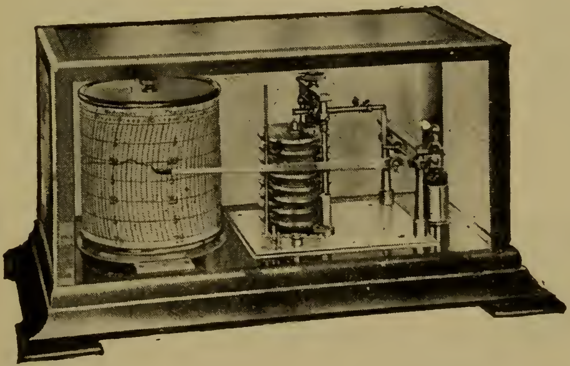

Fig. 201.—Barograph or recording barometer.

motion is magnified by the use of a series of rarefied boxes connected one to another, rather than a single box. The barograph may be seen at any government weather station.

196. Standard Conditions of Pressure and Temperature.—Since gas volumes are affected both by pressure and temperature, it necessarily follows that experimenters doing similar quantitative work on gases in different localities would not agree in their results, due to different conditions of pressure and temperature. In order to obviate this difficulty, *standard conditions* of pressure and temperature have been adopted. Uniformity is obtained by reducing all numerical work to these standards.

Standard conditions for gases are a pressure of 76 cm. of mercury and a temperature of 0°C. or 32°F. For ordinary calculations either 76 cm. or 30 in. may be used.

197. The Magdeburg Hemispheres.—The original Magdeburg hemispheres, invented by Otto von Guericke,[1] consist of two hollow metallic hemispheres fitting tightly together. The spheres are 22 in. in diameter and it is said that four teams of horses on either side were unable to separate them when the air was exhausted, due to the pressure of the air on the outer surfaces.

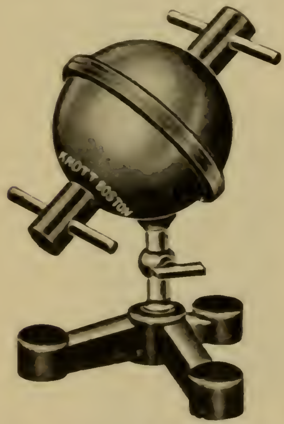

Fig. 202.—Magdeburg hemispheres.

The hemispheres shown in Fig. 202 are used for ordinary demonstrations and are 4 in. in diameter. The lower hemisphere terminates in a threaded stem which may be removed from the base and screwed into the plate of an air pump. When the air is exhausted, the outside pressure holding them together is so great that two students will experience great difficulty in separating them. In computing the total pressure tending to keep the hemispheres together, simply assume a circular plane whose diameter is the same as the diameter of the hemispheres. The curved area is not used on account of the fact that the various pressures, acting at right angles to the curved surface, do not all point in the same direction for each individual half. The components of these pressures, acting perpendicular to the circular plane assumed, comprise the total force acting. If the vacuum is perfect, the force necessary to pull apart the hemispheres shown in Fig. 202 will be 4 × 4 × .7854 × 14.7 or 184.72 lb.

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[1] Otto von Guericke (1602–1686). German physicist and astronomer. Mayor of Magdeburg. Made many experiments with liquids and gases. Constructed the first air pump in 1605. Inventor of the Magdeburg hemispheres which four teams of horses could not separate.

Questions and Problems

1. State the general characteristics of gases.

2. What pressure is exerted by the atmosphere at sea level?

3. What is the average density of air at sea level and at 0°C.?

4. What is meant by the height of the homogeneous atmosphere?

5. Describe an experiment to prove that air has weight.

6. Describe an experiment to prove that air exerts pressure.

7. Describe Torricelli's experiment.

8. Describe Pascal's experiment.

9. How would you verify Pascal's experiment in the laboratory?

10. Describe the construction and operation of a mercury barometer.

11. Describe the construction and operation of an aneroid barometer.

12. Is the barometer a good weather prophet? Explain.

13. How would you determine the altitude by means of a barometer?

14. State clearly what is meant by standard conditions of temperature and pressure. Why were standard conditions adopted?

15. Describe the original Magdeburg hemispheres. How would you compute the force necessary to separate a pair of such hemispheres? Assume a vacuum within.

16. What is the weight of a column of mercury 30 in. high and 1 sq. in. in cross-section? What pressure does the column exert?

17. What is the weight of a column of mercury 76 cm. high and 1 sq. cm. in cross-section? What pressure does the column exert?

18. A water barometer reads 33 ft. What is the pressure of the air?

19. Find the weight of the air in a room 20 × 30 × 12 ft. Assume standard conditions.

20. What will the barometer normally read at the top of the Woolworth building 792 ft. high?

21. If the atmosphere had the same density throughout as at the earth's surface, how high would it extend in miles? Assume the height of the barometer to be 30 in.

22. If the pressure within the Magdeburg hemispheres (Prob. 15) is sufficient to sustain a 2-inch column of mercury, what force will be necessary to separate them?

198. Boyle's Law.[1]—Robert Boyle[2] was the first man to make a study of the relation of a confined gas and the pressure exerted by the gas. He stated, as a result of his investigations, that, during all volume and pressure changes for a given gas, the product of the volume and the pressure will remain constant. For example, suppose that we have 4 cu. ft. of air confined under a pressure of 1 atmosphere. The product of the volume and pressure will be 4 × 1 or 4. Suppose, further, that we increase the pressure against the gas to 2 atmospheres. The volume will be reduced to 2 cu. ft. and the product of the volume and pressure will be 2 × 2 or 4. The above relation is usually stated:

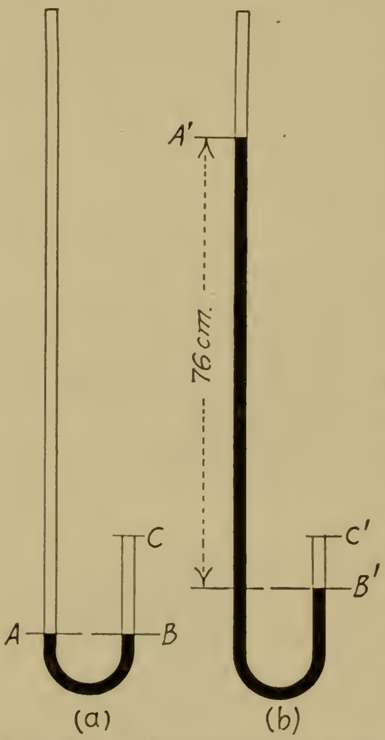

FIG. 203.—Apparatus for verifying Boyle's law.

The temperature remaining constant, the volume of a confined gas will vary inversely as the pressure acting upon it.

Boyle's law may be stated algebraically:

$$V_1 : V_2 = P_2 : P_1 \text{ or } V_1P_1 = V_2P_2.$$

The following simple experiment will verify Boyle's law. Figure 203(*a*) represents a glass tube of uniform bore, bent as shown and closed at *C*. Mercury is poured into the open end through a funnel and the apparatus adjusted until mercury levels A and B are the same. The volume of the confined air (proportional to BC) is then under a pressure of 1 atmosphere or 76 cm. of mercury. More mercury is poured into the tube, see Fig. 203(b), until the level of the mercury in the open part is 76 cm. above the level in the closed part. The confined gas is now under a pressure of 2 atmospheres or 152 cm. of mercury and the volume of the confined air (proportional to $C'B'$) will be reduced to ½ its former size. *By doubling the pressure we have halved the volume.*

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[1] Boyles law is not exact, but is close enough for practical purposes.

[2] Robert Boyle (1627–1691). English physicist and chemist. Experimented extensively in pneumatics.

It is evident, in the above case, that the density of the air was doubled when the pressure was doubled. Hence: *the density of a confined gas varies directly as the pressure upon it.* Algebraically:

$$D_1 : D_2 = P_1 : P_2.$$

If the volume remains constant, the weight of a confined gas varies directly as the pressure it exerts. Algebraically:

$$W_1 : W_2 = P_1 : P_2.$$

Questions and Problems

1. State Boyle's law.

2. Describe an experiment to verify Boyle's law.

3. State the relation between the density of a confined gas and the pressure upon it.

4. State the relation between the weight of a confined gas and the pressure exerted by the gas, volume constant.

5. A vessel contains 5 liters of air at standard pressure. What will the volume be if the pressure is changed to (a) 780 mm.? (b) 740 mm.?

6. 10 cu. ft. of illuminating gas is at a barometer pressure of 30 in. What will be the pressure, if the volume is compressed to 7 cu. ft.?

7. The gasoline tank of an automobile lacks 10 gallons of being full. The engine pump communicating with the tank is allowed to run until the air gauge on the dash reads 2 lb. Find the weight of the air in the tank. 1 cu. ft. of air at standard conditions weighs .0807 lb.

8. A 10 cu. ft. tank of helium gas (density at standard conditions =.0112 lb./cu. ft.) is at a pressure of 760 mm. of mercury. Helium is pumped into the tank until the pressure is 50 lb. Fnd (a) the density of the gas; (b) the weight of the gas.

9. The weight of the air in a room is 50 lb. at 29.5 in. of mercury. What will be the weight at 30 in. of mercury?

10. A 1922 Buick six cylinder motor has a bore of 3.375 in. and a stroke of 4.5 in. Assuming the clearance to be 1 in., what pressure will the mixture of air and gasoline vapor exert under full compression? What will be the total pressure against the cylinder head? Take the atmospheric pressure as 15 lb. Assume constant temperature.

11. Repeat as above for an eight cylinder Cadillac motor. The bore is 3.125 in. and the stroke is 5.125 in.

199. The Aeroplane.—Since the aeroplane is heavier than air, the lifting force is not due to the same reason as in the case of a balloon. The lifting force is due to the reaction or thrust of the air against the planes as the machine is driven through the air at a high rate of speed. The velocity is obtained by means of a special wood propeller driven by a gasoline motor of special design. Aeroplanes have proven indispensable in war for scouting, bombing, etc. They have yet to prove their success as heavy cargo carriers.

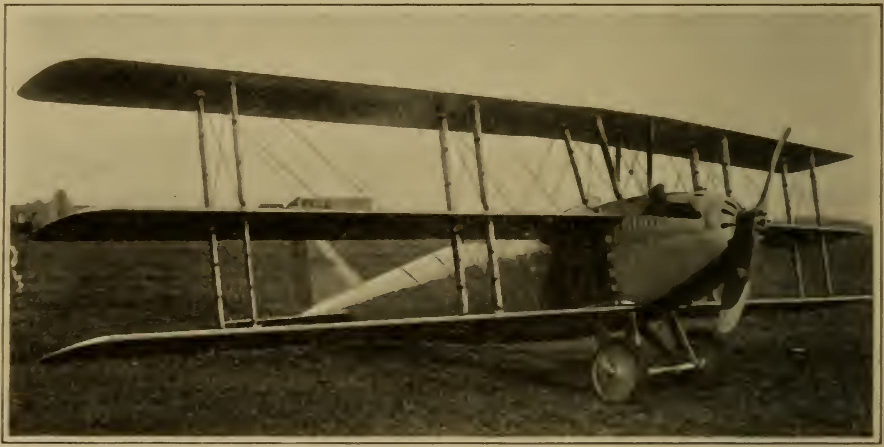

Fig. 204.—Curtiss model 18-*T* triplane.

The aeroplane shown in the above cut is a Curtiss Model 18-*T* Triplane. The over-all length is about 23 ft. and the over-all height about 10 ft. The wing span is nearly 32 ft. The machine weighs 1,825 lb. and will carry a gross weight of 2,901 lb. It has a maximum horizontal flight velocity of 163 m.p.h. and a climbing speed of 15,000 ft. in 10 minutes. At 2,500 r.p.m., the motor horsepower is rated at 400.

200. The Balloon.—The lifting ability of a balloon depends upon the buoyancy of the air. Just as a body submerged in water is buoyed up by the weight of the water displaced, so a body submerged in air is buoyed by the weight of the air displaced. The buoyant force of water is 62.5 lb. for each cubic foot displaced. Since air is about 1/773 as heavy as water, the buoyant force of a cubic foot of air will be 62.5/773 or approximately .08 lb. A balloon containing a vacuum would have a tremendous lift, but would be crushed by the outside pressure. To obtain a suitable lifting force, the balloon is filled with some very light gas as hydrogen, helium, etc. Helium is today regarded as the most satisfactory gas. It is heavier than hydrogen, but is not inflammable like hydrogen. The gas densities given below are at standard conditions, *i.e.*, 0°C. and 76 cm. of mercury:

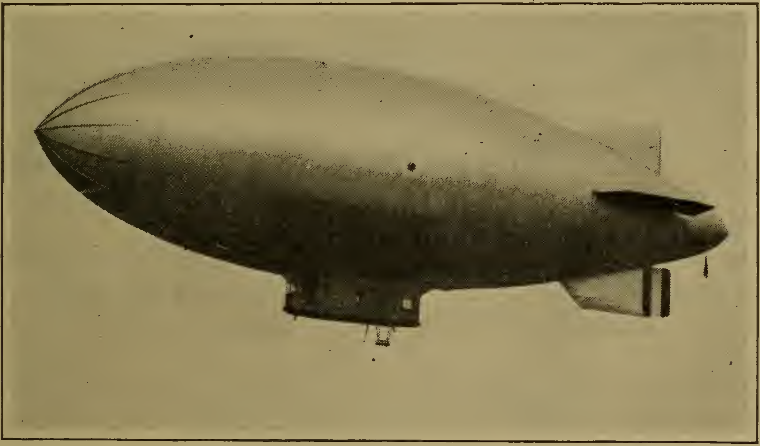

Fig. 205.—U. S. Army type *AC* dirigible.

Hydrogen	.0056 lb./cu. ft.
Helium	.0112 lb./cu. ft.
Illuminating gas	.0500 lb./cu ft.
Air	.0807 lb./cu. ft.

The *lift* exerted by a balloon depends upon the density of the gas with which the balloon is filled. It is equal to the weight of the air displaced by the envelope minus the weight of the gas in the envelope. The *ascensional force* is the force with which the balloon leaves the ground. It is equal to the *lift* minus the weight of the envelope, rigging, car, passengers, etc.

Figure 205 shows a type *AC* dirigible recently built for the U. S. Army. It is 167 ft. long, has a gas capacity of 187,000 cu. ft. and a cruising speed of about 65 m.p.h. The car is entirely closed and will carry 8 people.

An Army observation balloon of the *R* type is 90 ft. long, 29 ft. in diameter and has a gas capacity of 37,000 cu. ft. The envelope, rigging, car, etc., weigh 1,000 lb.

Suppose we wish to find the *total lifting effect* and the *ascensional force* at ground conditions, if the envelope is filled with pure hydrogen.

Solution:

.0807 − .0056 = .0751 lb. lifting effect per cu. ft. of hydrogen,
37,000 × .0751 = 2,778.7 lb. total lifting effect,
2,778.7 − 1,000 = 1,778.7 lb. ascensional force.

Suppose now that we wish to find the *ascensional force* of the above balloon if filled with commercial hydrogen (98 per cent. pure). Assume the 2 per cent. impurity in the hydrogen to be air.

Solution:

37,000 × .98 = 36,260 cu. ft. of pure hydrogen,
36,260 × .0751 = 2,723.1 lb. total lifting effect,
2,723.1 − 1,000 = 1,723.1 lb. ascensional force.

Questions and Problems

1. Explain the lifting effect of an aeroplane.

2. What is meant by the lift and ascensional force of a ballon?

3. State how each of the above is determined.

4. State the various gases used in ballons. What is the advantage of each?

5. Why does a submarine either sink to the bottom or float on the surface when the power is cut off, while a balloon, on ascending, will reach a certain height and float?

6. A spherical ballon 50 ft. in diameter is filled with pure hydrogen. Find: (*a*) the buoyant force of the air; (*b*) the weight of the hydrogen; (*c*) the total lift.

7. Repeat Problem 6, using pure helium.

8. Repeat Problem 6, using 98 per cent. pure hydrogen.

9. Repeat Problem 6, using 92 per cent. pure helium.

10. A spherical balloon has a capacity of 40,000 cu. ft. and is filled with commercial hydrogen (98 per cent. pure). The balloon and car weigh

450 lb. Two passengers weighing 160 lb. each are carried. Find: (*a*) the total lift; (*b*) the ascensional force.

11. An 84,000 cu. ft. U. S. Army dirigible is filled with pure hydrogen. The gas bag, car, motors, crew, etc., weigh 6,300 lb. What is the ascensional force?

201. The Siphon.—The siphon is a device used to transfer liquids from one receptacle to another. It consists of a bent tube of unequal arms. A rubber tube may be used for ordinary liquids. Referring to Fig. 206, let us study the operation of a siphon. Assume that water is flowing from vessel *A* into vessel *B* through the bent tube. Since *EF* is shorter than *CG*, it is evident that the weight of the liquid in the latter arm is greater than in the former. The upward pressure at *F* is the atmospheric pressure minus the pressure of the column *EF*. The upward pressure at *G* is the atmospheric pressure minus the pressure of the column *CG*. Therefore the upward pressure at *F* exceeds the upward pressure at *G*. It is evident that there will be a flow from the point of greater pressure at *F* to the point of less pressure at *G*. The flow will continue until *F* and *G* are at the same level and hence at the same pressure. If *EF* is higher than 34 ft., the siphon will not work, as water will not rise above that point in an exhausted tube. If mercury is used, *EF* must not exceed 30 in.

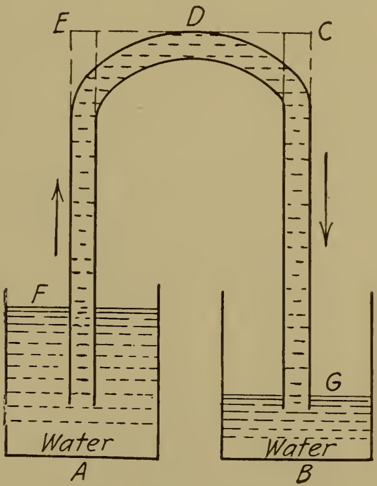

Fig. 206.—Siphon.

202. The Air Pump.—The so-called air pump is an apparatus for exhausting air from vessels. It was invented in 1650 by Otto von Guericke. With a good pump, a very high degree of vacuum may be obtained. Figure 207 shows the construction of a simple air pump. It consists of a cylinder (*C*) with a tight-fitting piston (*P*). V_1 and V_2 are valves. On the upward stroke, a vacuum is formed under the piston in the cylinder, V_1 closes automatically and V_2 opens, and the air in the bell glass (B) passes in part to the cylinder to fill up the vacuum and equalize the pressures. On the downward stroke, V_2 closes and V_1 opens, allowing the air in the cylinder to pass out. The above process is repeated, each time a portion of the air in B being removed. Since only a fraction of the air is removed at each stroke, it will be seen that a perfect vacuum can never be obtained. The air pump may be converted into a compression pump by opening V_2 to the atmosphere and attaching the receptacle, into which the air is to be compressed, to the tube at V_1.

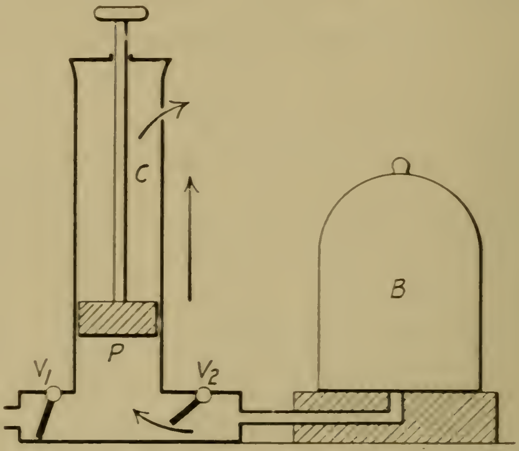

Fig. 207.—Air pump.

203. The Air Brake.—Figure 208 shows the construction of a simple Westinghouse air brake. T is a tank carried by each separate unit, in which the engine pump maintains, through pipe (P), a pressure of about 75 lb. While the engine pressure is acting in P, the triple valve V maintains communication between P and T. If the pressure is cut off in P, either at the engine or by accidental uncoupling of the pipe line,

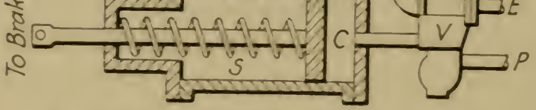

Fig. 208.—Westinghouse air brake.

communication between *P* and *T* is cut off at *V* and communication is opened between the tank (*T*) and the cylinder (*C*). Thus the compressed air in *T* forces the piston to the left in the cylinder, setting the brake shoes against the wheels. To remove the friction of the brakes, pressure is again turned on in *P*. The connection between *T* and *C* is thus closed, the air from *C* exhausts at *E* and the spring (*S*) moves the piston back to its original position.

204. Liquid Pumps with Reciprocating Parts.—*Reciprocating pumps* ordinarily depend upon atmospheric pressure for their operation. The *lift* pump (Fig. 209) consists of a cylinder with a tight-fitting piston. The piston carries a valve (*V*) and the lower part of the cylinder has a valve (V_1). Whenever the piston is drawn up, *V* closes and V_1 opens, water being forced up into the cylinder by the pressure of the air. On the down stroke V_1 closes, trapping the water already in the cylinder. At the same time *V* opens, allowing the trapped water to pass into the upper part of the cylinder. On the next up stroke *V* closes, trapping the water above the piston and forcing it out for delivery. Simultaneously V_1 opens and the previous cycle is repeated. The pump will not operate if

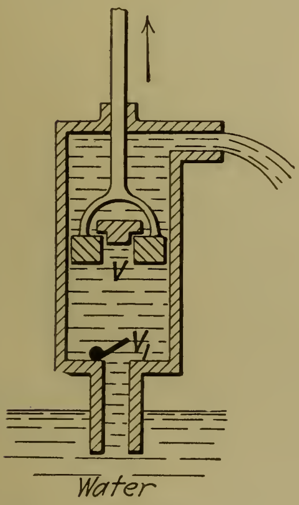

FIG. 209.—Lift pump.

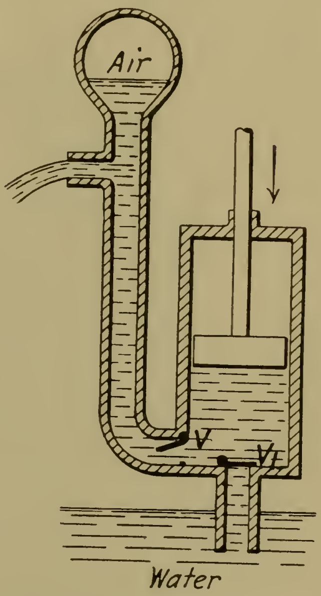

FIG. 210.—Force pump.

V_1 is much more than 30 ft. above the surface of the supply water.

Figure 210 shows a *force* pump. V_1 opens as the piston is drawn up, and water is forced up into the cylinder by atmospheric pressure; at the same time V closes. On the down stroke V_1 closes, trapping the water in the cylinder, and V opens, allowing the water to pass into the delivery tube. On the next up stroke V closes, V_1 opens and the cycle is repeated. The air chamber at the top of the delivery tube causes the water flow from the orifice in a *steady stream*, instead of intermittently. There is no reasonable limit to the height that the water may be forced, provided that V_1 is not too far above the water supply.

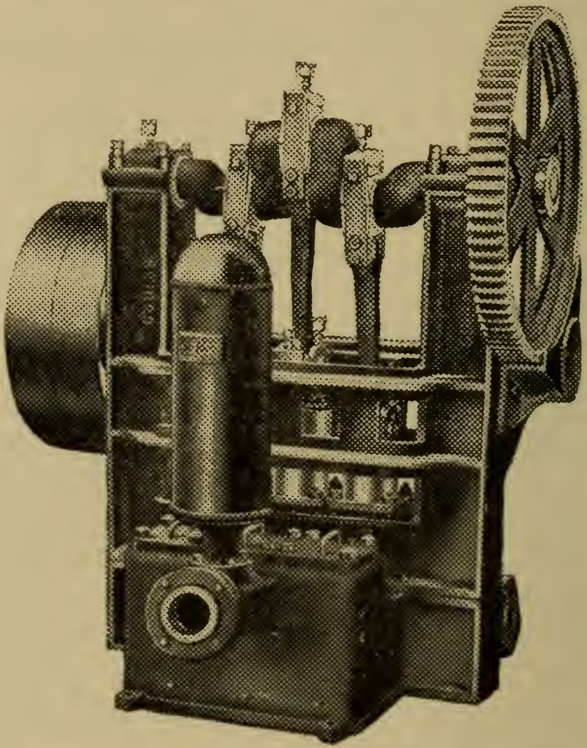

Fig. 211.—Goulds "Triplex" water pump.

Figure 211 is from a photograph of a Goulds single-acting "Triplex" pump. This type of pump is very widely used. It has a maximum working pressure of 300 lb. At this pressure, it will elevate water to a height of nearly 700 ft. Attention is called to the large air chamber in front.

205. Liquid Pumps with Rotating Parts.—Pumps with rotating parts have come into great prominence during the past few years. Figure 212 shows a *gear pump*. Its operation will be clear from an examination of the figure. This type of pump is used when the volume of liquid to be pumped is small. Many automobiles make use of gear pumps to actuate the oil circulation in the motor.

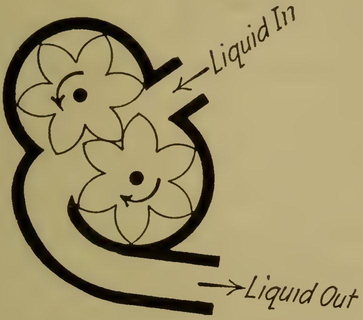

Fig. 212.—Gear pump.

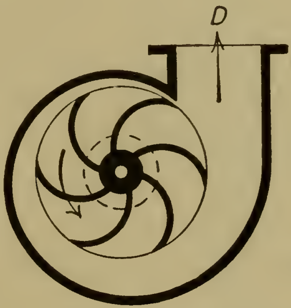

Fig. 213—Exposed section of a centrifugal pump.

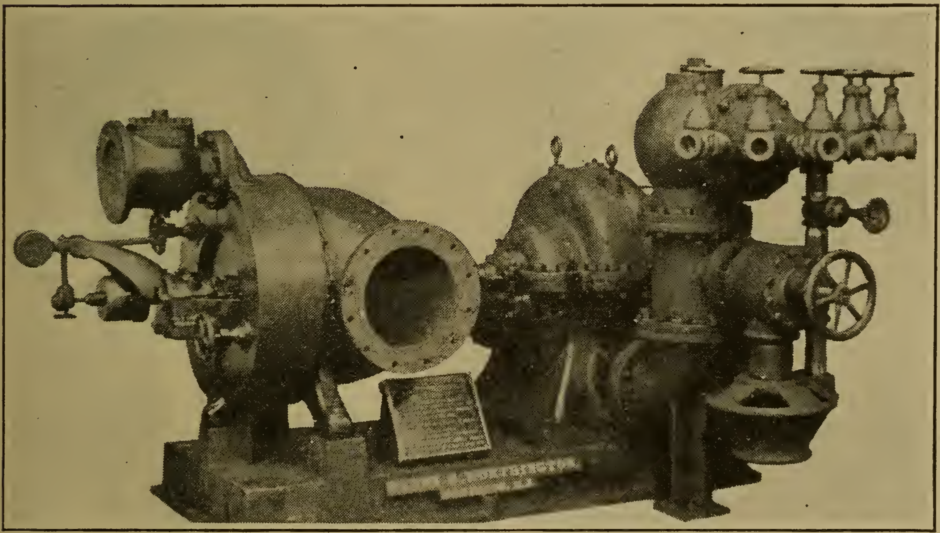

Fig. 214.—Worthington centrifugal fire pump.

Centrifugal pumps have been used for some time for low pressure purposes, such as circulating the water in internal combustion engines. They are now accepted as the proper kind of pumps for delivering liquids against high heads.

Those designed for high pressure are either electrically or steam turbine driven. In principle the centrifugal pump is a reaction turbine working backwards. Its construction will be seen from Fig. 213. The liquid enters at the center (shown by the dotted circle). As it strikes the blades, it is thrown toward the circumference of the casing. The liquid passes into the delivery pipe (*D*) with a pressure depending upon the design and speed of the pump.

Figure 214 shows a Worthington centrifugal pump used for fire purposes. It is turbine driven and will furnish 1,500 gallons of water per minute against a pressure of 100 lb.

206. Instruments for Measuring Pressure.—The commercial form of pressure gauge used on steam boilers, gas tanks, etc. (Fig. 215) is graduated in lb./sq. in. This type of gauge is designed to register the pressure *in excess* of atmospheric. Thus, if the gauge reads 100 lb./sq. in., the actual pressure of the gas under test is 115 lb./sq. in. The vacuum gauge (Fig. 216) is used to measure the degree of rarefaction in a closed gas container and is graduated in inches. Zero in. corresponds to a pressure of 15 lb. and 30 in. corresponds to a vacuum or zero lb. Hence, if the gauge reads 15 in., the actual pressure is 15/30 of 15 or 7.5 lb.

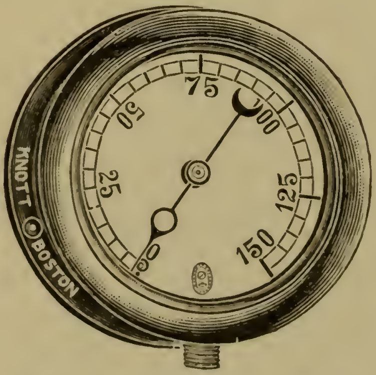

Fig. 215.—Pressure gauge.

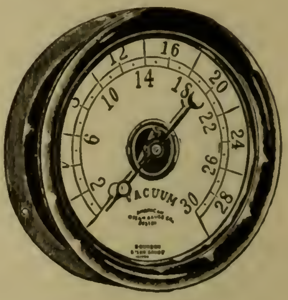

Fig. 216.—Vacuum gauge.

Figure 217 shows a laboratory model to illustrate the pressure and vacuum gauge. The hollow curved tube communicates with the gas under test. Whenever there is an increase in pressure, the tube tends to straighten, as a piece of garden hose when the water is turned on. The free end of the tube moves out and communicates its motion to a lever, the teeth on the extremity of which mesh with a pinion carrying the indicator. If the pressure decreases, the tube will bend in, allowing the indicator to move in the opposite direction, due to the spirally wound spring with which the indicator is connected. The indicator will remain stationary when a vacuum has been obtained.

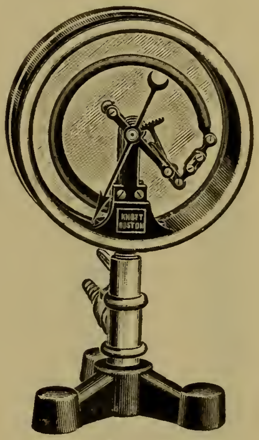

Fig. 217.—Working parts of a pressure gauge.

The open-arm manometer shown in Fig. 218, may be used for pressures above or below atmospheric. It consists of a tube bent as shown, open at *A*, containing a liquid of known density and connected to the gas container at *C*. If the pressure in the container is greater than atmospheric, the liquid in arm *A* will rise above the level of the liquid in arm *B*. The height of the liquid in *A* over the height in *B* determines the excess of the pressure in the container over atmospheric. The atmospheric pressure plus the excess pressure indicated gives the actual pressure exerted by the gas. If the confined gas is under a pressure of less than one atmosphere, the liquid in *B* will rise above the level in *A*. The excess of the atmospheric over the actual pressure exerted by the gas under test is computed from the difference in height of the liquid columns. The actual pressure exerted will be the atmospheric pressure, as determined by the barometer, minus the pressure as indicated by the liquid columns.

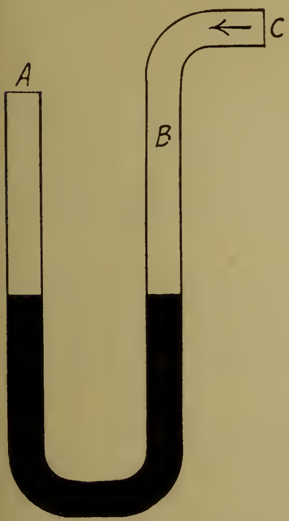

Fig. 218.—Open-arm manometer.

The closed-arm manometer shown in Fig. 219 is used to measure higher pressures than the open-arm manometer.

The tube is connected at C, as in the previous case, but arm A is closed. The liquid used is mercury and the space above the mercury in the closed arm is filled with air. The pressure is determined by means of the change in the height of the mercury columns and by the change in the air volume. At ordinary atmospheric pressure the mercury levels will be the same. Before C is connected to the confined gas, the position of the mercury levels is noted as well as the volume of the air in arm A. The barometer reading is also taken. As the arm is uniform in bore, the volume is proportional to the length of the air column. Length may therefore be used instead of volume. The pressure is computed from the change in the mercury levels and from the change in the length of the air column according to Boyle's law.

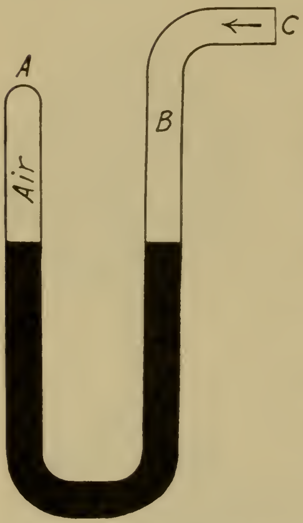

FIG. 219.—Closed-arm manometer.

Questions and Problems

1. Explain the action of the siphon.

2. Describe the construction and operation of an air pump. How may the air pump be converted into a compression pump?

3. Why is it impossible to obtain a perfect vacuum with an air pump?

4. Describe the construction and operation of the Westinghouse air brake.

5. Into what two classes may liquid pumps be divided? Give the construction and operation of the liquid pumps described in this chapter.

6. What is the difference between a pressure gauge and a vacuum gauge?

7. Describe the principle upon which the commercial gauge works.

8. Describe how pressure is determined with an open-arm manometer.

9. Describe how pressure is determined with a closed-arm manometer.

10. If in Fig. 206 EF is 20 in. and CG is 40 in., compute the upward pressure at F and the upward pressure at G. Barometer reads 30 in.

11. Assuming the diameter of C in Fig. 208 to be 12 in. and the pressure in T to be 75 lb./sq. in., what is the total pressure against the piston, if connection between T and C is open? State two reasons why the piston rod will not transmit the entire amount of the total pressure

12. If the reading of a pressure gauge is 25 lb./sq. in., what is the total pressure exerted by the gas under test?

13. If a vacuum gauge reads 20 in., what is the actual pressure of the gas under test?

14. The open-arm manometer (Fig. 218) is connected at *C* to a gas tank through a two-way valve. When the valve is opened to the air, the water levels are the same. When the valve is opened to the gas tank, the level in *A* is 3 in. above the level in *B*. Find the actual gas pressure in the tank.

15. Repeat Problem 14, if the level in *B* is 2 in. higher than in *A*.

16. Find the pressure of the confined gas in problem 14, if the level in *A* is 20 mm. higher than the level in *B*. Give answer in Kg./cm^2.

17. Before connection to a gas tank, the level of mercury in the closed arm of a manometer containing mercury is 2 cm. higher than in the opposite arm. After connection to the gas tank, the difference in mercury levels is 10 cm. and the air column is only half as long What is the actual pressure of the gas in the tank?

CHAPTER XXII

FALLING BODIES; CENTRIFUGAL FORCE; THE PENDULUM

SECTION 1. FALLING BODIES

207. Effect of Gravity on Falling Bodies.—Peculiar as it may seem to the student, gravity acts with equal effect on all bodies. If a heavy body and a light body are dropped from the same height at the same time, they will reach the ground simultaneously, provided that we neglect the resistance of the air. The air exerts a retarding effect on falling bodies, which depends upon the surface exposed. For example, a piece of aluminum weighing 5 lb. will fall somewhat more slowly than a piece of gold weighing 5 lb., due to the fact that the aluminum offers more area to the air. In a vacuum, however, they will fall with identical speeds. This may be proved as follows. Figure 220 represents a glass tube 4 ft. long and closed at one end. The lower end terminates in a petcock with an air pump attachment. Within the tube is a feather and a penny. If the tube is quickly inverted, the penny will be seen to fall more rapidly than the feather. If the air is then withdrawn from the tube and the experiment repeated, the feather and penny will be seen to fall with equal velocities. Hence we may arrive at the conclusion that *bodies, falling from the same height in a vacuum, will fall equal distances in equal lengths of time.* As air resistance is difficult to determine, it will not be taken into account in the solution of problems.

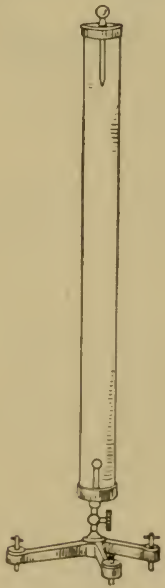

FIG. 220.—Apparatus to show that all bodies fall at the same rate in a vacuum.

208. The Acceleration of Gravity.—It has been determined by experiment that the acceleration of gravity is constant; that is, a freely falling body will be imparted an equal gain in velocity for each succeeding second. Starting with a velocity of zero, the body will have a velocity of 32.16 ft./sec. at the end of the first second; 64.32 ft./sec. at the end of the second second, etc. Thus we have an example of uniformly accelerated motion. The force of gravity varies slightly from place to place. At New York, the acceleration of gravity (symbol "g") is about 32.16 ft. per second per second or 980 cm. per second per second. It is usually written 32.16 ft./sec.^{2} or 980 cm./sec.^{2} During the first second, a freely falling body will travel 16.08 ft. or 490 cm.

209. Freely Falling Bodies.—We may now construct the following table for freely falling bodies, allowing D to represent $\frac{1}{2}g$ or the distance passed over during the first second. Since the acceleration is constant, the body will gain $2D$ in velocity each second and will pass over during each succeeding second $2D$ more than in the previous second.

t	v	s	S
1	$2D$	D	D
2	$4D$	$3D$	$4D$
3	$6D$	$5D$	$9D$
4	$8D$	$7D$	$16D$

in which

t = the time in seconds,
v = the velocity at the end of any particular second,
s = the distance passed over during any particular second,
S = the total distance passed over at the end of a given number of seconds.

Substituting $\frac{1}{2}g$ for D, it is evident that:

1. $v = gt$
2. $s = \frac{1}{2}g(2t - 1)$
3. $S = \frac{1}{2}gt^2$.

210. Bodies Rolling Down an Incline.—The acceleration for bodies rolling down an incline will be less than g. It is found by multiplying g by the height (h) of the plane over the length (l) of the plane.

$$\textit{Acceleration on an incline} = g \times h/l$$

Since h/l is equal to the sine of the angle of inclination, the following formula may be used:

$$Acceleration\ on\ an\ incline = g \sin \theta$$

211. Bodies Projected Vertically Downward.—In case a body is projected vertically downward from a state of rest (*e.g.*, a ball thrown down from a high building), the formulas given in the last paragraph must be changed to read:

1. $v = Initial\ velocity + gt$
2. $s = Initial\ velocity + \frac{1}{2}g(2t - 1)$
3. $S = Initial\ velocity \times t + \frac{1}{2}gt.^2$

212. Bodies Projected Vertically Upward.—If a body is projected vertically upward, the acceleration of gravity is negative; *i.e.*, the body will lose 32.16 ft./sec. or 980 cm./sec. until a velocity of zero is obtained. Starting from zero the body will return, the time of ascent and descent being equal, as well as the initial and final velocity. The time of ascent $(t) = v/g$.

Questions and Problems

(Assume g = 32 ft./sec.^{2} or 980 cm./sec.^{2})

1. Describe an experiment to show that all bodies fall at the same rate in a vacuum.

2. Explain what is meant by the acceleration of gravity.

3. Find v and S for a body freely falling from rest for 6 sec.

4. A body is rolling down a frictionless inclined plane 20 ft. long and 5 ft. high. Give the acceleration in feet and centimeters.

5. A ball is dropped from the Woolworth Building at a point 600 ft. above the sidewalk. Find the time of descent and the velocity on striking the walk.

6. In problem 5, how far did the ball travel in the fourth second? In the fourth and fifth seconds together?

7. How long will it take a spherical body to roll down a 10 per cent. grade, if the grade is 100 meters long?

8. What distance did the body in the previous problem pass over during the second second? What was the final velocity?

9. A stone is thrown vertically downward from a height of 200 ft. with an initial velocity of 10 ft./sec. (*a*) With what velocity did it strike the ground? (*b*) How long was it in the air? (*c*) How far did it travel in the second second?

10. A body is projected vertically upward with a velocity of 100 meters per sec. (*a*) How long was it in rising? (*b*) How high did it rise? (*c*) How long was it in the air? (*d*) How far did it travel in the fifth sec.? (*e*) With that velocity did it strike the ground.

11. A golf ball is dropped from a height of 200 ft. and ½ sec. later a second ball is dropped. How far apart will they be when the first ball strikes the ground?

213. Bodies Projected Horizontally.—If a body is dropped from a certain point and another body is projected horizontally from the same height at the same time, both bodies will reach the ground at the same instant. The second body will advance horizontally at a uniform rate of speed, but will curve downward in a parabolic path due to the action of gravity.

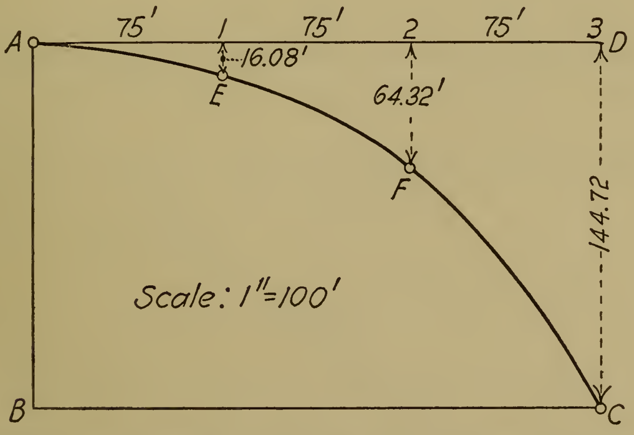

FIG. 221.—*AEFC* represents the path of a body projected horizontally from *A*.

AEFC (Fig. 221) represents the path of a body projected horizontally from *A* with a velocity of 75 ft./sec. For convenience we will assume that *A* is 144.72 ft. above the earth, so that the time in the air will be exactly three seconds. At the end of the first sec., the body will have advanced horizonally a distance of 75 ft. and gravity will have drawn it 16.08 ft. toward the earth. Therefore, at the end of the first second, the body will be at *E*. At the end of the second second the body will have advanced 75 ft. more horizontally and gravity will have drawn it 48.24 ft. nearer the earth or 64.32 ft. below the line *AD*. Hence, at the end of the second

second, the body will be at *F*. Similarly, it can be shown that the body will be at *C* at the end of the third second. The distance *BC* is called the *range*. The actual path of the body is called the *trajectory*.

Suppose we have a body projected horizontally from a height of 257.28 ft with a velocity of 1,000 ft./sec. It is required to find: (1) the time of descent; (2) the vertical velocity on striking; (3) the range.

Solution:

1. $S = 1/2\ gt,^2$ $257.28 = 16.08\ t^2$, $t^2 = 16$, $t = 4$ sec.
2. $v = at$, $v = 32.16 \times 4 = 128.64$ ft./sec.
3. $1{,}000 \times 4 = 4{,}000$ ft.

214. Bodies Projected so that the Angle of Elevation is Less than 90°.—Suppose a body, projected with a velocity of 200 ft./sec. from *A*, makes an angle of 40° with the ground (Fig. 222). Were it not for gravity, the body would continue at the same rate indefinitely in the straight line *AG*. On account of gravity, the body will be 16.08 ft. below *B* at the end of the first sec., 64.32 ft. below *C* at the end of the second second; 144.72 ft. below *D* at the end of the third sec., etc. The actual path of the body will be parabolical.

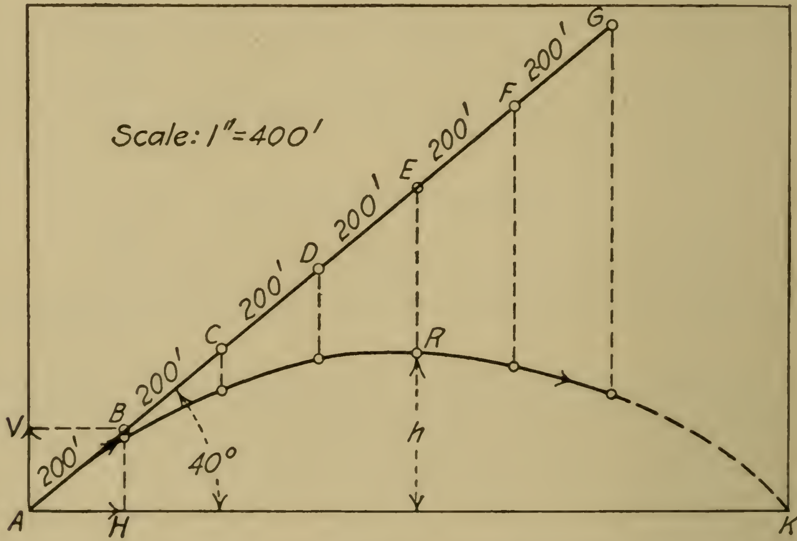

FIG. 222.—*ARK* represents the path of a body projected from *A* at an angle of 40° with the horizontal.

To solve problems in the above case, it is necessary to resolve the initial velocity into vertical and horizontal components (V and H) and consider them as separate velocities. Using data as in the previous paragraph, suppose we wish to find: (1) the time of ascent; (2) the time in the air; (3) the final vertical velocity; (4) the greatest vertical height (h); and (5) the range.

Solution:

First it is necessary to resolve 200 ft./sec. into its vertical and horizontal components. By trigonometry:

$$V = 200 \times \cos 50°,\ V = 200 \times .643 = 128.60 \text{ ft./sec.}$$
$$H = 200 \times \cos 40°,\ H = 200 \times .766 = 153.20 \text{ ft./sec.}$$

We may now consider the body to have an initial vertical velocity of 128.60 ft./sec. and a uniform horizontal velocity of 153.20 ft./sec.

1. $t = v/g,\ t = 128.60/32.16 = 4$ sec.
2. $4 \times 2 = 8$ sec.
3. Final vertical velocity = initial vertical velocity = 128.60 ft./sec.
4. $S = \frac{1}{2} gt,^2\ S = 16.08 \times 16 = 257.28$ ft.
5. $153.2 \times 8 = 1{,}225.60$ ft.

Problems

(Assume $g = 32$ ft./sec.^{2} or 980 cm./sec.^{2})

1. Construct a graph showing the path of a body projected horizontally from a point 400 ft. above the ground with a velocity of 100 ft./sec.

2. Construct a graph showing the trajectory of a body projected at an angle of 50° with the ground with a velocity of 400 ft./sec.

3. A projectile is discharged with a horizontal muzzle velocity 100 meters/sec. at a height of 500 meters above the ground. Find: (*a*) the time of descent; (*b*) the vertical velocity on striking; (*c*) the random or range.

4. A bullet discharged horizontally with a velocity of 800 ft./sec. has a range of 4,000 ft. Find: (*a*) the time the bullet is in the air; (*b*) the height of the bullet before discharge.

5. A ball is shot from a cannon at an angle of elevation of 60° with an initial velocity of 1,200 meters/sec. Find: (*a*) the time of ascent; (*b*) the time in the air; (*c*) the final vertical velocity; (*d*) greatest vertical height reached; (*e*) the range.

6. A baseball is batted from the home plate to the center fielder, a distance of 200 ft., with an average horizontal velocity of 60 ft./sec. Assuming that the ball starts 4 ft. above the ground and is caught 4 ft. above the ground, what is the greatest vertical height reached by the ball?

SECTION II. CENTRIFUGAL FORCE

215. Nature of Centrifugal Force.—The particles composing a rotating body have a tendency to "fly off" in a straight line at a tangent to the circle described by the individual particle. Suppose, for example, that we take particle *P* on the circumference of a rotating fly wheel, as shown in Fig. 223. Since every body tends to continue its motion in a straight line (Newton's first law of motion), it is evident that *P* has a tendency to leave the rim of the wheel and travel in a line shown by the arrow *A*. This tendency, which is really a reaction due to inertia, gives rise to a pull *away* from the center of the circle and must be overcome by an equal and opposite force *toward* the center. The force with which the particle tends to leave the center is known as *centrifugal force.* The equal and opposite balancing force is known as *centripetal force.*

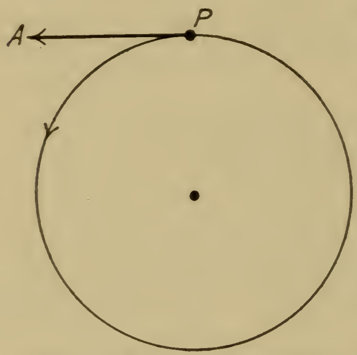

Fig. 223.—Particle *P* has a tendency to "fly off at a tangent" due to centrifugal force.

216. Effects and Uses of Centrifugal Force.—Centrifugal force occasions many interesting results, some of which are made use of mechanically. Centrifugal force no doubt caused the earth, when it was in a plastic state, to become bulged at the equator. On curves, railway tracks are constructed higher on the outside than on the inside so as to act against the overturning tendency of centrifugal force. The curves at the Sheepshead Bay automobile track were built at a slant to prevent skidding, as racing cars travel at a speed in excess of 100 *m.p.h.*

Laundries make use of centrifugal force in drying clothes. The wash is placed in a large perforated cylinder. As the cylinder rotates, the water tends to fly out. The cream separator operates on the principle of centrifugal force. The milk is rotated at a high rate of speed. The heavier portion gathers at the edge of the container, leaving the lighter cream at the center where it is drawn off.

Figure 224 shows a model of a governor used on low-speed steam engines to maintain a constant fly wheel speed. Due to centrifugal force, the balls tend to move out as the speed of rotation increases. The movement of the balls operates a lever which in turn operates the steam valve, cutting down the amount of steam admitted to the cylinder. If the speed becomes too low, the balls return toward the center of rotation, admitting a greater quantity of steam.

Medium- and high-speed engines make use of a shaft governor carried by the flywheel. It operates on the eccentric in such a way that the steam cut-off is retarded or accelerated according to conditions. If the engine tends to speed up, the governor, acting centrifugally, cuts off the steam sooner; if the engine tends to slow down, the action is reversed. Early cut-off decreases the *h.p.* and a later cut-off increases the *h.p.*

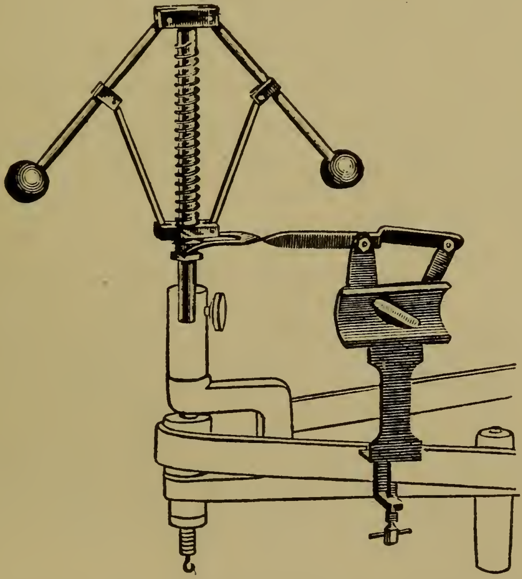

FIG. 224.—Model of a steam governor.

Many automobile trucks have a centrifugal arrangement to prevent excessive speed. A governor is used which limits the supply of air and gas delivered to the cylinders. Certain automobiles have also a centrifugal device for regulating the advance and retard of the spark.

217. Determination of Centrifugal Force.—In actual practice, we are usually interested in bodies revolving about some fixed point. Centrifugal force varies directly as the weight of the body and as the square of the velocity of revolution; inversely as the radius of revolution. Since centrifugal force is equal to centripetal force, one formula will suffice for both.

$$\textit{Centrifugal force} = \frac{Wv^2}{gr},$$

in which, W = the weight of the body; v = the linear velocity of the body at its center of mass; g = the acceleration of gravity; and r = the radius of revolution (the distance from the center of mass to the center of revolution). In the English system, pounds and feet are used; in the c.g.s. system, grams and centimeters are used.

Questions and Problems

(Assume g = 32 ft./sec.^{2} or 980 cm./sec.^{2})

1. What is centrifugal force? Carefully explain the cause of centrifugal force.

2. What is centripetal force? How does it compare in value with centrifugal force? Is centripetal force useful? Explain.

3. Give several instances showing the practical application of centrifugal force to mechanisms.

4. Give the formula for centrifugal force.

5. A body weighing 10 lb. is whirled around at the rate of 100 r.p.m. If the radius of revolution is 5 ft., what centrifugal force is developed?

6. An automobile weighing 3,000 lb. is rounding a curve at the rate of 40 m.p.h. If the radius of curvature is ¼ mile, what friction must there be between the road and tires to prevent skidding?

7. A flywheel weighing 300 lb. is rotating 1,500 times per minute. There is an unbalanced weight of 5 lb. acting 3 ft. from the center. Find the load on bearings due to centrifugal force.

SECTION III. THE PENDULUM

218. The Pendulum.—The ordinary pendulum consists of a bob suspended by a thread, cord, rod, etc., and capable of oscillation about a fixed point. If the weight of the supporting medium is negligible, the *length* of a pendulum is the distance from the point of support to the center of mass of the bob. The *amplitude* is the linear distance from the point of rest to the farthest position of swing. The *period* or *time* of vibration is the number of seconds necessary for a complete swing over and back. A "seconds pendulum" is one which makes a half-vibration in one second. Thus, the period of a "seconds pendulum" is 2 seconds. The length of such a pendulum at New York is approximately 39 in. or 100 cm.

219. Why a Pendulum Vibrates.—A vibrating pendulum is a good example of what is known as *simple harmonic motion*. Harmonic motion is a forward and back motion, in which the maximum velocity is at the center, decreasing to zero at either end.

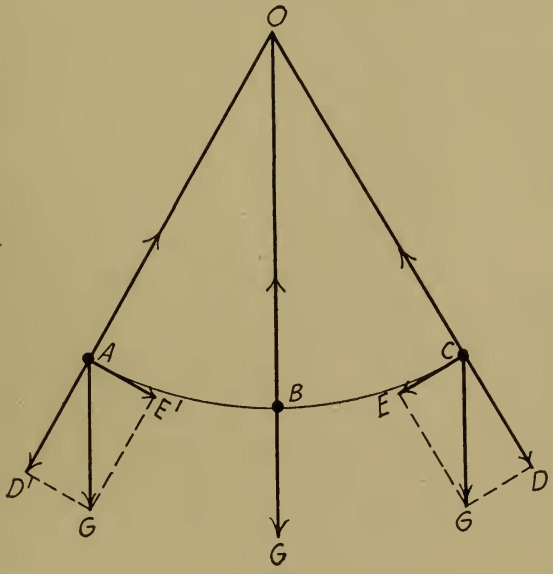

FIG. 225.—Diagram to show how gravity produces the oscillations of a pendulum.

A pendulum set into vibration will continue to vibrate with succeedingly smaller amplitudes, until it comes to a position of rest. The force tending to continue the vibration is *gravity* and the force eventually bringing the pendulum to rest is *friction*.

Let us see exactly how gravity acts with respect to a pendulum. Suppose (Fig. 225) that the pendulum bob is at rest at

B. Gravity (G), acting vertically downward, produces merely a tension in the supporting cord OB. and there is no tendency toward motion. If now the bob is drawn over to A, gravity may be resolved into two components, AD' and AE'. AD' produces tension in OA, while AE', acting tangent to the arc AB, tends to produce motion. As A swings to the right, AE' decreases in value, until at B it is zero. At B there is sufficient kinetic energy (friction neglected) to carry the bob to C. At C gravity may again be resolved into two components, CD and CE. CD produces tension in OC, while CE tends to produce motion. As C swings to the left, CE decreases in value, until at B it is zero. At B the bob has sufficient kinetic energy (friction neglected) to carry it to A, whereupon the cycle is begun again. Were it not for friction, the to-and-fro motion would continue indefinitely. In actual practice, the arc of oscillation gradually decreases on account of friction, eventually bringing the pendulum to rest. The pendulum of a clock and the balance wheel of a watch receive energy from an outside source (spring) and continue to vibrate until the energy of the spring is exhausted.

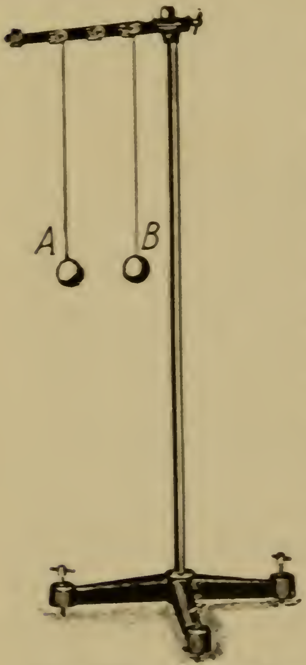

Fig. 226.—Apparatus for studying laws of the pendulum.

220. Laws of the Pendulum.—The mass of a pendulum does not affect its vibration rate. This is proved by the following simple experiment. Referring to Fig. 226, we have two pendulums of equal length but different weight. They are oscillated through small amplitudes and the vibrations of each are counted for one minute. It will be found that each pendulum has made the same number of vibrations.

For small amplitudes, the vibration rate is independent of the arc of swing. This may be proved by oscillating one of the pendulums in Fig. 215 through different short arcs. The number of vibrations per minute will be the same in each case.

We know from experience, however, that the vibration rate of a pendulum depends upon the length of the pendulum: the shorter the length the greater number of vibrations in a given time. Suppose (Fig. 227) we have three pendulums, *A*, *B* and *C*, of like weight and material and with lengths of 81, 64 and 49 cm. respectively. The square roots of the lengths are then in the ratio of 9 : 8 : 7. Each pendulum in turn is set swinging through a small amplitude and the number of vibrations per minute counted. The periods of vibration are then determined. It will be found that the periods are in the ratio of 9 : 8 : 7, proving that the period of vibration is directly proportional to the square root of the length.

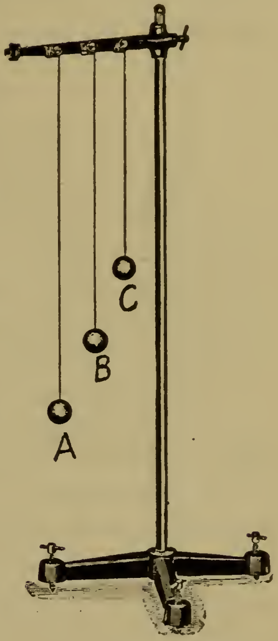

Fig. 227.—Apparatus for studying laws of the pendulum.

Since the force of gravity varies from place to place, it will be evident from Fig. 225 that an increase in the value of "*g*" will result in a decrease in the period of vibration. The period varies inversely as the square root of the acceleration of gravity.

Laws of The Pendulum Summarized

1. *The period of vibration is independent of the mass,*
2. *For small amplitudes, the period of vibration is independent of the amplitude,*
3. *The period of vibration varies directly as the square root of the length,*
4. *The period of vibration varies inversely as the square root of the acceleration of gravity.*

The laws in 3 and 4 above may be incorporated in the following equation:

$$T = 2\pi\sqrt{\frac{l}{g}},$$

in which T is the period or time of a complete vibration in seconds; l the length of the pendulum; and g the acceleration due to gravity at the particular locality. Thus, knowing the length and period of a pendulum, the value of g may be readily determined.

Questions and Problems

(Assume $g = 32$ ft./sec.^{2} or 98° cm./sec.^{2})

1. What is a pendulum?

2. Define the following terms with respect to a pendulum: length, amplitude, period of vibration, seconds pendulum.

3. Show that a pendulum illustrates simple harmonic motion.

4. What is the length of a seconds pendulum at New York?

5. State the laws of the pendulum.

6. Incorporate the laws of the pendulum in a single equation.

7. Two pendulums are respectively 4 and 9 in. in length. Compare their periods of vibration.

8. The period of a pendulum is 2 sec. What will the period be if the length is doubled?

9. A pendulum makes 10 *v.p.m.* How many *v.p.m.* will it make if the length is made one half as great?

10. Find the length of a second pendulum if $g = 980$ cm.; 990 cm.

11. A suspended plumb line makes 10 complete vibrations in one minute. How long is it? Give answer in ft.

12. A plumb line 40 ft. long is dropped from a chimney. What is its period of vibration? How many *v.p.m.* does it make?

13. A clock pendulum is 12 in. long. How many seconds will the clock gain in 24 hr., if the length is shortened to 11 in.?

APPENDIX

USEFUL INFORMATION

Pi, $\pi = 3.1416$.
Circumference of a circle $= d \times \pi$.
Area of a circle $= \pi r^2$ or $d^2 \times .7854$.
Area of a sphere $= 4\pi r^2$.
Volume of a sphere $= 4/3\pi r^3$.
Lateral surface of a cylinder = circumference of base × altitude.
Volume of a cylinder = area of base × altitude.

ENGLISH AND METRIC EQUIVALENTS

1 inch = 2.54 cm.
1 mile = 1.61 Km.
1 pound = 453.6 g.
1 liquid quart = .946 l.

1 meter = 39.37 in.
1 kilometer = .62 mi.
1 kilogram = 2.20 lb.
1 liter = 1.057 liquid qt.

DENSITY OF COMMON SUBSTANCES

1 cu. ft. of water at 4°C. weighs 62.4 lb.
1 cu. in. of water weighs .036 lb.
1 c.c. of water at 4°C. weighs 1 g.
1 cu. ft. of air at standard conditions weighs .0817 lb.
1 c.c. of air at standard conditions weighs .00129 g.
1 gallon (231 cu. in.) of water weighs 8.32 lb.
1 cu. ft. of brass (cast) weighs 527 lb.
1 cu. ft. of copper (cast) weighs 553 lb.
1 cu. ft. of ice weighs 57.2 lb.
1 cu. ft. of iron (cast, gray) weighs 442 lb.
1 cu. ft. of mercury weighs 848 lb.
1 cu. in. of mercury weighs .49 lb.

UNITS FREQUENTLY USED

"g" at New York $= 32.16$ ft./sec.^{2}
"g" at New York $= 980.2$ cm./sec.^{2}
Length of a seconds pendulum at New York = 99.3 cm.
1 dyne = .00102 g.

1 gram = 980 dynes.
1 pound = 445,000 dynes.
1 erg = 1 dyne centimeter.
1 joule = 10,000,000 ergs.
1 horsepower = 33,000 ft. lb./min.
1 horsepower = 550 ft. lb./sec.
1 horsepower = 746 watts.
1 kilowatt = 1,000 watts.
1 horsepower = 746/1,000 kilowatt (use 3/4).
1 kilowatt = 1,000/746 horsepower (use 4/3).

SPECIFIC GRAVITY OF COMMON SUBSTANCES

Solids		Fluids	
Aluminum (hard drawn)	2.7	Air	.00129
Brass (cast)	8.4	Alcohol	.80
Copper (cast)	8.9	Chloroform	1.5
Gold (cast)	19.3	Ether	.736
Ice	.918	Gasoline	.66–.69
Iron (gray, cast)	7.1	Kerosene	.79
Iron (wrought)	7.8	Linseed oil (boiled)	.94
Nickel	8.6	Mercury	13.6
Platinum	21.4	Neat's foot oil	.91
Silver (cast)	10.5	Turpentine	.87
Tin (cast)	7.3	Water (distilled)	1.00
Zinc (cast)	7.1	Water (sea)	1.03

TENSILE STRENGTH

Cast iron	18,000 lb./in.^{2}
Wrought iron	50,000 lb./in.^{2}
Mild steel	70,000 lb./in.^{2}

COMPRESSIVE STRENGTH

Cast iron	90,000 lb./in.^{2}
Wrought iron	38,000 lb./in.^{2}
Mild steel	80,000 lb./in.^{2}

SHEARING STRENGTH

Cast iron	25,000 lb./in.^{2}
Wrought iron	40,000 lb./in.^{2}
Mild steel	50,000 lb./in.^{2}

MODULUS OF ELASTICITY FOR TENSION AND COMPRESSION

Cast iron	15,000,000 lb./in.^{2}
Wrought iron	25,000,000 lb./in.^{2}
Mild steel	30,000,000 lb./in.^{2}

MODULUS OF ELASTICITY FOR SHEAR

Cast iron	6,000,000 lb./in.^{2}
Wrought iron	10,000,000 lb./in.^{2}
Mild steel	12,000,000 lb./in.^{2}

DECIMAL EQUIVALENT PARTS OF AN INCH

1/64	.0156	33/64	.5156
1/32	.0313	17/32	.5313
3/64	.0469	35/64	.5469
1/16	.0625	9/16	.5625
5/64	.0781	37/64	.5781
3/32	.0938	19/32	.5938
7/64	.1094	39/64	.6094
1/8	.125	5/8	.625
9/64	.1406	41/64	.6406
5/32	.1563	21/32	.6563
11/64	.1719	43/64	.6719
3/16	.1875	11/16	.6875
13/64	.2031	45/64	.7031
7/32	.2188	23/32	.7188
15/64	.2344	47/64	.7344
1/4	.25	3/4	.75
17/64	.2656	49/64	.7656
9/32	.2813	25/32	.7813
19/64	.2969	51/64	.7969
5/16	.3125	13/16	.8125
21/64	.3281	53/64	.8281
11/32	.3438	27/32	.8438
23/64	.3594	55/64	.8594
3/8	.375	7/8	.875
25/64	.3906	57/64	.8906
13/32	.4063	29/32	.9063
27/64	.4219	59/64	.9219
7/16	.4375	15/16	.9375
29/64	.4531	61/64	.9531
15/32	.4688	31/32	.9688
31/64	.4844	63/64	.9844
1/2	.5	1	1

Trigonometric Functions

A	Sin	Cos	Tan	*A*	Sin	Cos	Tan
0	0.000	1.000	0.000				
1	0.017	0.999	0.017	46	0.719	0.695	1.04
2	0.035	0.999	0.035	47	0.731	0.682	1.07
3	0.052	0.999	0.052	48	0.743	0.669	1.11
4	0.070	0.998	0.070	49	0.755	0.656	1.15
5	0.087	0.996	0.087	50	0.766	0.643	1.19
6	0.105	0.995	0.105	51	0.777	0.629	1.23
7	0.122	0.993	0.123	52	0.788	0.616	1.28
8	0.139	0.990	0.141	53	0.799	0.602	1.33
9	0.156	0.988	0.158	54	0.809	0.588	1.38
10	0.174	0.985	0.176	55	0.819	0.574	1.43
11	0.191	0.982	0.194	56	0.829	0.559	1.48
12	0.208	0.978	0.213	57	0.839	0.545	1.54
13	0.225	0.974	0.231	58	0.848	0.530	1.60
14	0.242	0.970	0.249	59	0.857	0.515	1.66
15	0.259	0.966	0.268	60	0.866	0.500	1.73
16	0.276	0.961	0.287	61	0.875	0.485	1.80
17	0.292	0.956	0.306	62	0.883	0.469	1.88
18	0.309	0.951	0.325	63	0.891	0.454	1.96
19	0.326	0.946	0.344	64	0.898	0.438	2.05
20	0.342	0.940	0.364	65	0.906	0.423	2.14
21	0.358	0.934	0.384	66	0.914	0.407	2.25
22	0.375	0.927	0.404	67	0.921	0.391	2.36
23	0.391	0.921	0.424	58	0.927	0.375	2.48
24	0.407	0.914	0.445	69	0.934	0.358	2.61
25	0.423	0.906	0.466	70	0.940	0.342	2.75
26	0.438	0.898	0.488	71	0.946	0.326	2.90
27	0.454	0.891	0.510	72	0.951	0.309	3.08
28	0.469	0.883	0.532	73	0.956	0.292	3.27
29	0.485	0.875	0.554	74	0.961	0.276	3.49
30	0.500	0.866	0.577	75	0.966	0.259	3.73
31	0.515	0.857	0.601	76	0.970	0.242	4.01
32	0.530	0.848	0.625	77	0.974	0.225	4.33
33	0.545	0.839	0.649	78	0.978	0.208	4.70
34	0.559	0.829	0.675	79	0.982	0.191	5.14
35	0.574	0.819	0.700	80	0.985	0.174	5.67
36	0.588	0.809	0.727	81	0.988	0.156	6.31
37	0.602	0.799	0.754	82	0.990	0.139	7.12
38	0.616	0.788	0.781	83	0.993	0.122	8.14
39	0.629	0.777	0.810	84	0.995	0.105	9.51
40	0.643	0.766	0.839	85	0.996	0.087	11.43
41	0.656	0.755	0.869	86	0.998	0.070	14.30
42	0.669	0.743	0.900	87	0.999	0.052	19.08
43	0.682	0.731	0.933	88	0.999	0.035	28.64
44	0.695	0.719	0.966	89	0.999	0.017	57.28
45	0.707	0.707	1.000	90	1.000	0.000	Infinity

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